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TDR-930(2701-01)TN-1
PART I, NO. 6

Applied Research Management

Abstract Bulletin

(Part I)

Abstracts 1-1104 through 1-1202

DECEMBER 1961

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Prepared for DEPUTY COMMANDER AEROSPACE SYSTEMS
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
Inglewood, California

AEROSPACE CORPORATION

CONTRACT NO. AF 04(647)-930

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ABSTRACT

Part I, No. 6 is a bibliography, with abstracts, from unclassified literature presented on the subject of Flight Vehicle Power. Selected references in the field of materials are also included. All references are to primary sources.

Approved by K. B. Andrews
K. B. Andrews
Literature Research Group

AEROSPACE CORPORATION
El Segundo, California

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I. FLIGHT VEHICLE POWER

SECTION A - GENERAL

1-1104. AIRBORNE AUXILIARY POWER SOURCES. Vickers, Inc., Detroit, Rept. no. EE-1025-033-a. 10 Mar. 1958. 27p. illus. A61-8473.

Various chemical, electrical, and mechanical energy sources are compared against a typical system requirement calling for 5-20 hp of hydraulic and electrical energy for durations up to one-and-one-half hrs. The mechanical flywheel yields the lightest system for durations up to 1/2 or 2 min, and the reciprocating engine yields the lightest system above this duration. Silver-zinc cells and monopropellant turbines are competitive over most of the range, with the silver-zinc cell appearing particularly attractive for durations of 2 to 5 min or more. Hot gas servo systems are unattractive from the weight standpoint, and have other limitations. Compressed gases and mechanical springs are found to be prohibitively heavy.

1-1105. ANALYSIS OF TEMPERATURE DISTRIBUTION AND RADIANT HEAT TRANSFER ALONG A RECTANGULAR FIN OF CONSTANT THICKNESS. Seymour Lieblein. National Aeronautics and Space Administration, Washington, D. C., NASA TN D-196. Nov. 1959. 60p. illus. A61-5585.

A theoretical analysis is conducted of the steady-state radiant heat-transfer characteristics of rectangular fin plates of constant thickness with uniform heat source along the leading edge and no convection. Calculations of the variation of temperature and radiating effectiveness with distance from the heat source are made for infinite- and finite-length plates over a wide range of ratios of sink-to-source temperatures. Application of the solutions to a variety of environmental conditions is made possible through the determination of an equivalent sink temperature for the environment. Design parameters for minimizing plate volume are derived, and application of results to practical radiator considerations is indicated.

1-1106. RESEARCH AND DEVELOPMENT ON POWER SOURCES AND ENERGY CONVERSION, IN THE DEPARTMENT OF DEFENSE, AEC, AND NASA. Weapons Systems Evaluation Group. Inst. for Defense Analyses, Washington, D. C., Report no. 61-4/U (Abridged Version). 16 May 1960. 89p. Contract: SD-50. A61-3005.

This report involves a listing of the various research and development projects being supported by the Department of Defense, AEC and NASA. It also includes an evaluation of the categories into which the work is divided, a breakdown or an itemization of the funding.

1-1107. PLASMA PHYSICS AND THE PROBLEM OF CONTROLLED THERMONUCLEAR REACTIONS. M. A. Leontovich, ed. (Translated from the Russian). N. Y., Pergamon Press, 1961. 4v. QC791 A313.

This four-volume book is a compilation of papers resulting from investigations made during the years 1951-1958 at the Atomic Energy Institute of the U. S. S. R. Academy of Sciences into the problems of controlled thermonuclear reactions and related questions of plasma physics. Only papers which have not previously appeared in print are included. The collection is divided on a chronological basis; the responsible editor is Academician M. A. Leontovich. The papers are concerned primarily with the theory of plasma physics and magnetohydrodynamics, and contain sufficient experimental data for verification of the theory. Experimental instrumentation is described. There is no information about power producing equipment.

SECTION B - CHEMICAL SOURCES OF ENERGY

1-1108. BATTERY RESEARCH AND DEVELOPMENT CONFERENCE 11TH ANNUAL, PROCEEDINGS, 22-23 May 1957. Army Signal Research and Development Lab., Fort Monmouth, N.J., PB 137392 111p. illus. QC 603U58, 1957.

The following sessions were held:

New Dry Battery Structures
Dry Battery Materials
Secondary Batteries
Nickel-Cadmium Batteries
Solar Energy Devices
Nuclear Batteries

1-1109. DEVELOPMENT OF "RESERVE" AND "NON-RESERVE" TYPE HIGH RATE ZINC SILVER OXIDE "A" AND "B" BATTERIES. R. Brockman. Eagle-Picher Co., Joplin, Mo. Seventh Quarterly Report, 1 Nov. 1959-31 Jan. 1960. 31p. illus. Contract: DA-36-039-SC-75067, Proj. 3-18-03-707. A61-4232.

The work conducted during the past report period has been concerned chiefly with chemically heated, automatically activated, silver oxide-zinc batteries. Efforts were directed principally toward improving the activation characteristics. Among the variables studied were gas generators, pre-heater extensions, and air buffer tubes. The pre-heater extensions appeared to afford some improvement but the other features seem to effect no definite performance change. It appears that a basic design feature is responsible for all slow activation. The heat balance is the most probable factor. A 34% weight reduction was obtained in the light-weight batteries constructed during the past period. Additional light-weight batteries were constructed for further evaluation in view of the results obtained during the last quarter. The environmental tests performed on the light-weight batteries constructed this period are not conclusive. However, previous tests indicate that they may be capable of withstanding the environmental conditions as imposed on the BA-472/U battery. Development work was deferred during this quarter on activated stand studies, activation indicator studies, and separable activation systems.

1-1110. EVALUATION OF THE PERFORMANCE AND RELIABILITY OF THE BATTERY BA-481( )/U. Volume I. Charles E. Vark. Final Report, 9 June 1958 - 30 June 1960. Eagle-Picher Co., Joplin, Mo. 153p. Contract: DA-36-039-SC-78061. A61-8843.

This final report deals with the design, development, and evaluation of the reliability of the battery BA-481( )/U. The entire reliability program was conducted on the basis of the philosophy that if the test levels were sufficiently severe, a comparatively small number of samples could be utilized for testing without sacrificing confidence in the resulting reliability findings. Levels at four times specification were chosen for complete batteries, as well as sub-assemblies and components. Environmental conditions which presented problems to the original battery were elevated temperature during an activated stand period, 40 g vibration, and acceleration in the adverse position. The ability to sustain a 40-min activated stand at +140° F was greatly improved by the use of thicker separators in the battery cells. The vibration problem was solved with a compromise of 75% Lockfoam and 25% Epoxy potting, complimented by dipping the cell lugs in a Polyester solution prior to this potting. Acceleration in the adverse position (where the g forces moved the electrolyte out of the battery cells) was partially compensated for by incorporating a separator which had high electrolyte retention

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1-1110. (Cont.)

abilities. Along with this, it was recommended that the battery be mounted so that these extreme acceleration forces would be directed along less susceptible axes of the battery. This report presents all of the development and testing data of the components, as well as the complete battery assembly. Also presented are pictures and drawings of the test equipment and fixtures which were used. Manufacturing drawings and specifications are contained in a supplement to this report.

1-1111. EVALUATION OF SINTERED PLATE NICKEL CADMIUM STORAGE BATTERIES. New York Naval Shipyard. Material Lab., Brooklyn, Rept. no. NS 677-058. Final Report, 31 Oct. 1958. 10p. illus. AD 207 539-L. A61-10326.

The report outlines evaluation of six volt, sintered plate nickel cadmium batteries, designed for engine starting, by the Navy Material Laboratory. Accelerated discharge and recharge testing caused failure of all the batteries tested. Failure was determined to be due to breakdown of the cellophane separator material. It has been determined at other agencies that the sintered nickel cadmium battery operates more satisfactorily as a standby battery.

1-1112. FUEL CELLS...ELECTRICAL ENERGY FROM AN ELECTROCHEMICAL PROCESS. J. Weissbart and R. Ruka. Westinghouse Engineer, vol. 20, no. 4, July 1960, p. 108-10.

Hydrogen-oxygen (KOH), ion-exchange membrane, molten salt, and redox fuel cells are discussed. In addition, the high-temperature test cell with solid electrolyte (laboratory stage) is shown. Fuel cells offer the possibility of more efficient conversion of chemical to electrical energy than conventional electric power generation methods. An ideal fuel cell would use cheap fuels, be made of economical materials, operate at high efficiency, have high power output per unit volume and weight of cell, and a long life. It appears that the "low-temperature" cells should begin to find special purpose applications within the next few years. The use of fuel cells for large-scale power generation is still in question and will require either a drastic reduction in fuel and capital costs for low-temperature cells, or the development of an inexpensive, long-lived high-temperature cell to utilize low cost fossil fuels.

1-1113. HOT GAS FLIGHT SYSTEM SERVO CONTROLS. Presented at the S. A. E. Committee A-6 Symposium on Advanced Fluid Systems Technology, St. Louis, Missouri, 30 Sept. 1959. 16p. illus. 22 refs. A61-8408.

This report proposes the use of hot gas directly from a gas generator to provide auxiliary power for missiles, primarily for operating aerodynamic control surfaces. Hot gas servos have a weight advantage for this purpose over systems using hot gas to power auxiliary power generators and thus hydraulic actuators. Gas generators, hot gas servo motors and control system design are discussed.

1-1114. HYDROCARBON REGENERATION OF THE ANOLYTE IN A REDOX FUEL CELL. James C. Mailen. Florida Univ., Gainesville. Engineering and Industrial Experiment Station, Special Report no. 1. 18 Mar. 1960. 18p. illus. Contract: DAI-49-186-502-ORD(P)-860. A61-10314.

The importance of the regeneration step in redox fuel cells is very briefly discussed, and it is shown that there is little knowledge concerning the nature or extent of the reactions involved. Thermodynamic methods have been brought to bear upon the oxidation of lower normal paraffin hydrocarbons to alcohols in an effort to estimate the relative difficulty of a possible first step in the complete oxidation of the hydrocarbon to carbon dioxide and water. In the absence of adequate data a number of assumptions were necessary. These obviously limit the validity of the conclusion reached, but the errors which might have been so introduced appear to be too small to change them substantially. For the reaction $H_2O + Sn^{+4} + CH_4(aq) = Sn^{+2} + CH_3OH(aq) + 2H^+$ at one atmosphere pressure and 25° C, it is estimated that the overall free energy of reaction is $\Delta G_R = +15,330$ cal./g. mole CH_4. For the reaction $H_2O + Sn^{+4} + C_2H_6(aq) = Sn^{+2} + C_2H_5OH(aq) + 2H^+$ at one atmosphere pressure and 50° C, it is estimated that the overall free energy of

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reaction is ΔG_R = +8,310 cal./g. mole C_2H_6. It is therefore apparent, since ΔG_R is positive, that it is difficult to effect the reactions; under the conditions postulated. Furthermore, it appears that it will be quite difficult to provide the conditions necessary to make either of the above reactions proceed through the alcohol at low temperatures.

1-1115: IMPROVEMENT IN THE PERFORMANCE CHARACTERISTICS OF THE NICKEL-CADMIUM BATTERY. Arthur Fleischer. Final Report, 15 June 1957, including Fourth Quarterly Progress Report, 15 Feb.-14 May 1957. Nickel Cadmium Battery Corp., East Hampton, Mass. 80p. Contract: DA-36-039-SC-72318, Proj. no. 3-18-03-031. 45 refs. A61-6823.

Thin plate elements to meet modified BB403/U requirements using constant voltage charging showed conformance after trickle charge or open circuit stands exceeding 8 hrs. Thick plate elements with extra gas space in nylon jars are proposed for this use. Continuous cycling in a vacuum, 40 min discharge at C/2 and 60 min charge at 1.45 volt of a Deac 150 DK button cell gave a useful life of 1800 cycles to the specified 80% voltage without permanent loss in capacity. An abbreviated cycle test was studied. The literature, mainly patents, was reviewed to generalize the principles of design and operation of sealed Ni-Cd cells.

1-1116. INDUSTRIAL PREPAREDNESS STUDY OF MAGNESIUM DRY CELL BATTERIES - TYPE BA-270/U-XM. Nineteenth Quarterly and Final Report, 17 Feb. 1955-31 Dec. 1959. Mallory Battery Co., Div. of Mallory and Co., Inc., Cleveland. 10 Feb. 1960. 67p. Contract: DA-36-039-SC-66080. AD 235 157. A61-8279.

The purpose of this contract is to design, construct, and produce on a semi-commercial scale 3600 Magnesium Dry Cell Batteries, Type BA-270/U-XM, in accordance with the techniques and formulations outlined by the Battery Development Section, Power Sources Branch, Fort Monmouth, New Jersey for such batteries as described in this contract. Several attempts were made since 1955 to design, construct and produce batteries which will not fail the requirements. Finally in 1959 a third lot of preproduction batteries were made using 75% Type M and 25% African in the B_1 and B_2 sections. These gave acceptable tests and the pilot run of batteries was made in December 1959. The batteries were tested and on the basis of these tests the following conclusions may be drawn. The BA-270/U-XM batteries could not be made to give the required performance life with African manganese dioxide ore. The BA-270/U-XM batteries gave the required performance life by using 75% Type M chemical manganese dioxide and 25% African ore in the mix for the

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"B_1" and "B_2" sections and 100% Type M chemical manganese dioxide in the "A" section. Reducing the number of N size cells in the B_1 and B_2 from 30-30 and 30 to 26-26 and 27 increased the performance of the batteries. The magnesium bromide electrolyte must be free of all contamination which would react with the magnesium cans. The smaller cells, like the N size, are effected far more than larger cells like the D and F sizes, especially on 113° storage by electrolyte contamination.

1-1117. MAGNESIUM PRIMARY CELLS AND BATTERIES.
C. G. Birdsall. Mallory Battery Co., Cleveland. Final Report, 13 Dec. 1960. 31p. Contract: DA-36-039-SC-73233. AD 257 761. A61-8307.

The purpose of this contract is to develop and produce in pilot quantities various types of paperlined dry cells and battery packs using magnesium cans. The cells were made, assembled in BA-418/U and BA-414/U batteries and subjected to 113° and 70° storage and tests. The test program showed that pilot quantities of paper lined dry cells and battery packs could be successful using magnesium cans in accordance with techniques and formulations outlined by the Battery Development Section, Power Sources Branch, Fort Monmouth, New Jersey. All the batteries in this contract have been given satisfactory performance except those made with the N size cell, viz. BA-414/U-XM and BA-416/U-XM. Examination of the cells in the BA-414/U-XM and BA-416/U-XM shows that the welding of the connecting wires can contribute to low service, especially after 1130 storage, because the weld may pierce the 0.020 in. wall and cause drying out of the cells.

1-1118. PHASE II, PROTOTYPE AUXILIARY POWER SYSTEM.
Vickers, Inc., Detroit, Rept. no. 1065-045. 14 Aug. 1959. 44p. Contract: U-8586. A61-8472.

The results tabulated from the suitability test program confirm the durability and repeatability of the Vickers Hot Gas APS. A variance in propellant burning rate was noted during this testing program. A higher burning rate occurred which increased the output horsepower and inversely shortened the burning time. This had no effect on the success of the suitability tests.

1-1119. REDOX FUEL CELLS. L. G. Austin. Quarterly Progress Report No. 1, 1 Mar. - 1 June 1960. Pennsylvania State Univ. University Park. Coll. of Mineral Industries. June 1960. 8p. illus. Contract: DA-49-186-502-ORD-917. AD 243 588. A61-8280.

Examination of redox fuel cell literature has revealed no information of value on the kinetics of the fuel regenerator. Very little information on the rates of reaction of hydrogen and hydrocarbons with ion pairs has been found in the literature. A reactor has been designed and will be constructed in the next quarter. Various analytical techniques will be investigated. The theory of the loss of free energy in the regenerator has been worked out for simple reactions. Inetic parameters from the literature have been used to illustrate the voltage-current calculation for a hypothetical cell.

1-1120. RELIABILITY STUDY - HIGH RATE LECLANCHE WAFER CELLS. Martin Sulkes. First Annual Report, 1 Mar. 1960-15 Apr. 1961. United States Electric Mfg. Corp., N. Y., N. Y. 25 May 1960. 63p. illus. Contract: DA-36-039-SC-85266. A61-9877.

Phases I and II, Tooling and Pilot Production, has been completed. Work on the project has advanced into Phase III. The tool, jigs and dies necessary for the completion of Phase I were completed within the allotted time period without encountering any unusual problems. New methods of production of the wafer cell units were developed necessitating minor adjustments of equipment previously used for prior contracts. These were also accomplished within the required time period. Manufacture of the seventeen (17) Lots of wafer cell units as described in the Signal Corps Technical Requirements SCL-7510 with revisions proceeded as scheduled except that one lot of high temperature batteries was destroyed by malfunctioning of the heat chamber. These were subsequently replaced. Phase III, the testing of wafer cell batteries, has been partially completed for the first eleven (11) lots produced. All testing after three months storage has been completed for Lot a to s. Data on various characteristics of wafer batteries has also been included in this report.

1-1121. RESEARCH ON REDOX AND RELATED FUEL CELL SYSTEMS. Summary Report no. 9, 15 Oct. 1958-15 Apr. 1960. General Electric Co., Aircraft Accessory Turbine Dept., Lynn, Mass. 102p. illus. Contract: DA-44-009-ENG-3771. AD 241 300. A61-8289.

The objective of this program was to make basic studies to permit the design of an improved Redox fuel cell system with associated hydrogen generation equipment. The initial work under this contract consisted of the evaluation of organic, inorganic and complexed systems for use as intermediate oxidant couples; the evaluation of various acids as electrolytes for the couples; the determination of the stability of the titanyl-titanous reductant couple in sulfuric acid; and the measurement of the oxidation potential of air under various conditions with different catalysts and in solutions of different hydrogen ion concentrations. For the oxidant couple, many organic systems were investigated but none of those studied was found adequate for use in the Redox cell. Most failed from a potential point of view but some with promising potentials failed because of a lack of chemical stability. Inorganic couples were also investigated but none was found with a half cell potential between 1.0 and 1.23 volts that could be oxidized with air. Finally, complex couples were investigated but with unsatisfactory results. It was concluded that one of the major difficulties in the couple study was associated with the oxidation

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potential obtainable with oxygen in air. It was impossible to achieve a potential above 1.0 volts unless the bromine-bromide, nitric oxide system was used. The objective of the more recent work was to establish the overall design of a 1500 watt Redox fuel cell system operating from diesel fuel. On the basis of these studies, a preliminary design of an overall 1500 watt Redox fuel cell system was made. This included the conceptual design and thermodynamic analysis of a small, compact hydrogen generation system to establish the best possible efficiency. Experiments have shown that the allowable concentrations of CO and H_2S, in the hydrogen gas stream to regenerate the titanous-titanyl couple without poisoning, are lower than the concentration of these gases found in the output of the hydrogen generator. It therefore appears necessary to remove these poisons from the hydrogen stream. Polarization studies on single cells have shown that current densities as high as 100 amp/ft^2 can be achieved but at considerable sacrifice in cell efficiency. Preliminary design studies indicate that the present best capability of the Redox System is of the following order of magnitude: 1) Power density--0.2 kw/ft^3--for fuel cell pack alone and 0.1 kw/ft^3-including auxiliary components for regeneration, electrolyte interruption and volatile recovery; 2) thermal efficiency--40%-based on the higher heat of combustion of the hydrogen feed to the generator. Other studies on the hydrogen

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generator have shown the need for an improved and integral combustor-reformer design to reduce heat losses and to increase efficiency. A conceptual design which imbeds the combustor in the reformer unit promises to reduce heat losses to a tolerable level. A hydrogen generator system based on this principle and sized to supply hydrogen for the 1500 watt fuel cell system is optimistically estimated to have the following capability (these values make no provision for removal of CO and H_2S): Volume--3 ft^3; thermal efficiency--60%. Thus, at this state-of-the-art, the following is an optimistic order-of-magnitude estimate of the capability of an overall Redox fuel cell system operating from liquid hydrocarbons: This includes the hydrogen generator and fuel cell pack with its auxiliary components for regeneration, electrolyte interruption and volatile recovery and all necessary pumps, controls, valving, etc. However, it does not include provision for the removal of CO and H_2S. Power Density--0.04 kw/ft^3; thermal efficiency--25%.

1-1122. STUDY OF FUEL CELLS WITH SOLID ELECTROLYTES.
V. S. Daniel'bek, M. Z. Hints, et al. Trudy Chetvertogo Soveshchaniya Po Elektrokhimii, (1-16 Oktyabrya 1956)1959, p. 794-800. 17 refs. AD 255 376. A61-7665.

In the last few years considerable attention has been given to high temperature fuel cells with solid electrolytes and hydrogen-oxygen cells with an aqueous alkaline electrolyte, operating at high temperatures and pressures. However, no results have been obtained as yet which would make possible the technical use of fuel cells. In this report the results of certain investigations in the field of fuel cells with solid electrolytes, intended for operation at high temperatures are given. The results obtained confirm that fuel cells operating on coal or a gas-like fuel in an interval of temperatures from 500° to 1000° can theoretically have high efficiency (up to 100%) with an e. m. f. close to 1 volt.

1-1123. STUDY OF SEALED NICKEL-CADMIUM BATTERIES.
Paul Ritterman. Final Report, 1 Dec. 1958-31 Jan. 1960.
Sonotone Corp., Elmsford, N. Y. 73p. illus. Contract:
DA-36-039-SC-78249. AD 236 545. A61-8406.

The life cycling program, using size "D" hermetically sealed cells filled with varying concentrations and amounts of electrolyte, was concluded after 608 cycles. These cells are still operational (cycles limited by contract time). Results of periodic capacity tests made during the entire cycling program are shown. Testing of sample plates in an electrolyte flooded condition was concluded and results are presented. Ninety "1/2 C" sealed cells were constructed for the experiment to test the effects of cobalt addition to the positive plates, lithia addition to the electrolyte and variation of negative/positive capacity ratios. A test program for these cells was devised and completed. End of charge voltage and discharge capacities are shown. Three special plate frames each containing a negative plate were constructed. The rate of reaction with oxygen of cadmium plates was investigated, within a sealed chamber, under varying conditions of oxygen pressure, mole fraction of oxygen and electrolyte concentration. Data obtained and presented seems to indicate that electrolyte concentration has no effect on initial reaction rate and that both mole fraction of oxygen and total oxygen pressure affect the initial as well as overall rate of reaction. Nine "F" hermetically sealed

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cells were constructed with a special side opening so that it was possible to measure pressure build-up on charge and discharge by connection to a gauge. All data pertaining to cell construction is presented. Three of the hermetically sealed "F" cells were used in the experiment designed to test the effect of temperature and initial cell atmosphere on the charge and discharge characteristics of the sealed cell. The effects on pressure build-up during charge and discharge were also studied. Tests at 25° C with cells initially containing the ambient atmosphere have been completed. A relatively low recombination pressure (average--12.4 psig) was found for the three cells tested when they were charged at the 3 hour rate (1.8 amperes). Even on an overcharge of greater than 200% at this rate the recombination pressure remained at this level. Charge data and discharge data to various end points are summarized.

SECTION C - MAGNETOHYDRODYNAMIC SYSTEMS

1-1124. MAGNETOHYDRODYNAMIC ENERGY CONVERSION TECHNIQUES. Richard J. Rosa and Arthur R. Kantrowitz. Avco-Everett Research Lab., Everett, Mass., Research Rept. 86 (formerly Research note 120). Apr. 1959. 18p. illus. A61-4354.

This report gives an introductory account of the basic theory of magneto-hydrodynamic (MHD) generators, the characteristics of such devices, and the electrical properties of gases. Shock tube experiments which demonstrate some of the fundamentals of MHD flow are described.

1-1125. MAGNETOHYDRODYNAMIC GENERATORS - POWER FROM HIGH-TEMPERATURE GAS. Stewart Way. Westinghouse Engineer, vol. 20, no. 4, July 1960, p. 105-06.

A device that uses a fluid conductor to produce an electric current is a magnetohydrodynamic generator. Practical realization of MHD power depends upon the use of a conducting gas. The most practical means of obtaining the required partially ionized gas seems to be seeding of the gas with an alkali metal such as cesium or potassium; then the required ionization can be attained at temperatures between 4000 and 5000° F. There are materials that can tolerate this temperature. The overall efficiency of an MHD plant might be as high as 60%, compared to 40-42% for most modern conventional plants. Open and closed MHD systems are described. Future programs are outlined.

SECTION D - MECHANICAL DEVICES

1-1126. ANALYTICAL INVESTIGATION OF CYCLE CHARACTERISTICS FOR ADVANCED TURBOELECTRIC SPACE POWER SYSTEMS. Thomas P. Moffitt and Frederick W. Klag. National Aeronautics and Space Administration, Washington, D. C., NASA TN D-472. Oct. 1960. 29p. A61-2528.

An investigation was made of the relative influence of turbine inlet temperature, radiator temperature, and turbine efficiency on radiator area for Rankine cycles with rubidium, potassium, and sodium as working fluids. It was determined that, whereas turbine inlet temperature and turbine efficiency have gross effects on radiator size, for a given inlet temperature a considerable latitude in the selection of radiator temperature may be accepted with only minor effects on required radiator size. Also investigated was the influence on turbine efficiency and design of the factors that distinguish alkali-metal vapor turbines from conventional gas turbines. The turbine configuration was determined to be a function of the involved working fluids and rotor blade speed. For a given blade speed, the number of stages required for high turbine efficiency was found to vary directly with turbine specific work output, and therefore, to vary in the ratio 5 to 2. 5 to 1 for sodium, potassium, and rubidium, respectively. Lower blade speeds than employed in conventional gas turbines may be required to satisfy critical stress considerations resulting from the elevated temperatures involved

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and the criterion of long-duration reliability. This will increase the number of turbine stages necessary to obtain high turbine efficiency and consequently increase turbine weight. The question of moisture formation was discussed and a calculation was made to indicate the nature of the aerodynamic losses due to moisture content. Various means of reducing moisture content were considered, including mechanical removal, increased radiator temperature, inefficient expansion, superheat, and reheat. Sample calculations were made in most cases to indicate their comparative effectiveness and resultant penalty in required radiator area.

1-1127. TRANSISTORIZED FOUR-SEGMENT COMMUTATOR FOR A DIRECT-CURRENT MACHINE. Frederick L. Schwartz. Massachusetts Inst. of Tech., Cambridge. Electronic Systems Lab., WADC TR 59-682. Feb. 1960. 39p. illus. Contract: AF 33(616)-3984, Proj. no. 8149, Task no. 61098. 18 refs. A61-3001.

This report is concerned with the development and evaluation of an electronic four-segment commutator which is intended for use in place of the mechanical commutator in a d-c machine. The main features of this electronic commutator are: a) commutation is performed on the stator windings by means of an eight-switch arrangement; b) the rotor position signal for controlling the switching operations is obtained from two Hall generators mounted in the air-gap of a separate machine which is rigidly coupled to the shaft of the commutated machine; c) transistors are used as the switching elements and in the control circuitry; and d) the commutator switches are bilateral, allowing the machine to run either as a d-c motor or generator. A machine using the electronic commutator was successfully run as a d-c motor and generator at an input power level of 240 watts. The electronically commutated machine is capable of running at an input power level of 600 watts. Two

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sets of slip rings were the only sliding contacts required for the operation of the machine. A comparison between the electronic and mechanical commutator in terms of size, reliability, and efficiency shows that more work must be done, especially on solid-state switching devices, before the electronic commutator will be practical for moderate- and high-power machines.

1-1128. TRANSISTORIZED TWO-SEGMENT COMMUTATOR FOR A DIRECT-CURRENT MACHINE. D. M. P. Eisenlohr. Masachusetts Inst. of Tech., Cambridge. Electronic Systems Lab., WADC TR 59-683. Feb. 1960. 57p. illus. Contract: AF 33(616)3984, Proj. no. 8149, Task no. 61098. 31 refs. A61-3000.

This report covers the development of a fully electronic two-segment commutator, which was then experimentally used to demonstrate generator and motor operation of a d-c machine with a single winding armature. First, a short review is given of the brushless machines already existing and their similarities to synchronous machines. Their limitations are pointed out and a type of static bilateral inverter (commutator) is suggested, which would avoid these limitations. The main part of the report describes the development of a two-segment commutator using transistors for the commutator switches as well as for the control circuitry. The complete circuit consists of a position signal generator, mounted on the shaft of the machine, where the Hall effect is used for obtaining a signal indicative of rotor position without the use of mechanical contacts. This signal is converted into pulses by transistorized Schmitt triggers. These trigger pulses drive transistor

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1-1128. (Cont.)

control flip-flops, whose function is to turn on and off the power transistors responsible for commutating the armature. This inverter was shown to operate analogously to a mechanical two-segment commutator and some tests of its operation are reported.

SECTION E - NUCLEAR SOURCES OF ENERGY

1-1129. EFFICIENCY OF FISSION ELECTRIC CELLS. Clifford J. Heindl. California Inst. of Tech., Pasadena. Jet Propulsion Lab., Rept. no. 32-105. 25 May 1961. 29p. illus. Contract: NASw-6. A61-6325.

Electrical efficiencies are calculated for fission-electric cells of parallel plate, concentric sphere, and concentric cylinder geometries as a function of operating voltage and fuel layer thickness. For spherical and cylindrical cells, several ratios of outer to inner radii are included, covering the range which appears feasible for a reactor which is to be carried on a spacecraft. The calculations are simplified by ignoring the distribution of fission fragment masses, charges, and kinetic energies and utilizing average values for these quantities; a linear rate of energy loss is assumed for the first portion of the fragment trajectories, as they pass through the fuel layer. The calculated efficiencies decrease with fuel layer thickness, increase with the curvature of the electrodes and ratio of outer to inner electrode radii, and exhibit a maximum at operating voltages near one-half of maximum achievable potential.

1-1130. GENERALIZED REACTOR AND SHIELD WEIGHT RELATIONSHIP FOR SPACE VEHICLES. Thompson Ramo Wooldridge Inc., Cleveland, Rept. no. ER-3667. 22 Dec. 1958. 28p. illus. A61-3911.

The nuclear reactor with a metal vapor turbine and direct drive generator is one of the most promising ways to produce electrical power for space vehicles, particularly as power requirements increase. Reliability required for many missions appears attainable with hermetically sealed, in-line power packages which utilize the working fluid for lubrication and cooling. This report considers the portion of the power plant involving the reactor and the shield; it presents reactor requirements and a parametric analysis of the reactor and shield. The interrelations of reactor requirements are shown graphically. For powers below 100 MW, the hydride reactor is lighter. For missions requiring large power and longer life, the heavier beryllium oxide moderated reactor becomes more attractive. Factors involved in minimizing shield weight are discussed and their relationships are presented graphically. For small reactors, beryllium oxide types require heavier shielding.

1-1131. SPACE POWER. William W. T. Crane. Tenth International Astronautical Conference, London, 1959, p. 748-55.

This paper describes recent research and test data which indicate so far that a safe, reliable and practical radioisotope fueled auxiliary power supply can be built using existing technology. After extensive examination of the alpha-emitters available, it has been determined that only four isotopes have merit as heat sources. These are Curium-242, Polonium-210, Curium-244, and Plutonium-238. Potential availability and cost, plus the lack of hard gamma radiation, were the deciding factors in the selection of these four isotopes. The specific power, or watts/cm^3 of the above isotopes is the following: Polonium-210, 90.0; Curium-242, 256.0; Curium-244, 20.0; Plutonium-238 (PuC), 6.9; and Plutonium-238 (Pu), 9.3. The total amount (gamma and neutron radiation) of direct radiation is 0.0265 (1 yd, rem/hr) for Po-210; 0.0368 for Cm-242; 0.0128 for Cm-244; 0.00079 for Pu-238 (PuC); and 0.00054 for Pu-238 (Pu). These figures are the radiation associated with an unshielded isotope heat source, considering those gamma radiations that will escape from the fuel block. The source material is sealed in capsules of high-temperature, high-strength materials to assure safe containment under all anticipated conditions. In order to evaluate various heat source designs, cold simulated radioisotope fuels have been employed in a number of tests. These tests have included both low and high velocity impact tests. The

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contained radioisotope heat source was impacted against targets such as granite, concrete, and packed earth, at velocities varying from terminal velocity to three times terminal velocity. All specimens were heated to temperatures equivalent to impact temperature and fired from rocket sleds. All specimens that were fired at speeds equivalent to terminal velocities remained intact, although extensive deformation was encountered on impact with granite. These same radioisotope heat sources have been subjected to missile failure tests such as exploding mixtures of liquid oxygen and kerosene. Even when fuel blocks were heated to more than 2000° F and plunged directly into liquid oxygen (at almost 300° below zero), the test specimens failed to support combustion and survived intact. An experimental unit, SNAP-3B is described in detail. It uses Polonium-210 in encapsulated form. Each of the two stainless steel cylinders contained about 800 curie of activity, and was closed with a tapered plug. The plug was sealed by heliarc welding with 100% penetration. Situated about the contained heat source are 27 couples of doped lead telluride elements. These elements are doped with bismuth or sodium to provide N- and P-type semiconductors, with one N-type and P-type thermoelement defining a couple, and all connected in series. Each of the elements provides a parallel path for heat flow from the heat source to the container-radiator. Since the thermocouples must be

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electrically insulated from each other, mica sheet or ceramic coating is used between the hot junction and the heat source. The figure of merit of the doped lead telluride increases with decreasing temperature and counterbalances the decreasing Carnot efficiency. The overall efficiency, therefore, tends to remain constant. Subjected to vibration tests, these thermoelectric isotope generators showed some lowering of power output and some noise was observed during testing on oscilloscope, but in all cases within five minutes after the tests ceased the power returned to its original value. Acceleration up to 15 g have been placed on these generators for five minutes in each plane of symmetry with no effect. These generators have been subjected to 50 g shock tests with a rise time of less than one millisecond in each of the three mutually orthogonal directions with all generators satisfactorily operating after these tests. The long life and inherent reliability of isotopic power systems suggest numerous applications in the Age of Space.

SECTION F - SOLAR SOURCES OF ENERGY

1-1132. A COMPARISON OF SOLAR POWERPLANT SYSTEMS FOR SPACE VEHICLE APPLICATIONS. Robert A. Cocozella, Emery F. Boose, et al. Avco Mfg. Corp. Research and Development Div., Wilmington, Mass., Rept. no. RAD-TR-9-60-23. 13 Oct. 1960. 40p. illus. Contract: AF 04(647)-305, Proj. no. WS107A-2. 9 refs. A61-1540.

A comparison of several solar power plant systems for space vehicle use was made. The objective was to study the various characteristics of such systems and to show the relative values of each without the selection of a particular one for a vehicle. The comparison involved primarily the power conversion device; in particular, the following: thermionic, thermoelectric, mercury vapor turbine generator, and solar cells. The basis for comparison postulates a continuous 3 kw electrical output for one year. The thermionic system is the one of lowest weight since the comparatively high radiator temperature results in low radiator weight. In addition, the use of liquid coolants is avoided. In turn, the thermoelectric approach requires large radiator weight and area because of the comparatively low cold junction temperature. The large ratio of radiator area to cold junction area necessitates a liquid coolant loop to transfer the heat. The mercury turbine possesses a good efficiency and places modest demands on the solar collector focusing characteristics. However, it is generally more complex than the

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thermionic and thermoelectric systems and is slightly heavier than the former. Solar cells are expensive and prove to be heavy and fragile but are the simplest of all systems.

1-1133. HIGH EFFICIENCY SILICON SOLAR CELLS. Pierre Lamond and Paul Berman. Third Semiannual Summary Report, 1 July-31 Dec. 1960. Transitron Electronic Corp. Wakefield, Mass. 32p. illus. Contract: DA-36-039-SC-85250, Proj. no. 3A99-09-001, Task no. 3A99-09-001-03. AD 257 494. A61-8273.

A summary of the process used at Transitron for the p on n solar cells is presented. These have been superceded by the more radiation resistant n on p type cells. Problems in optimizing the junction depth of solar cells are discussed. The results of diffusion experiments are presented. The calibration of solar cell standards and artificial light systems for the testing of solar cells is discussed. Special attention is given to the problems encountered in using a tungsten artificial light source to determine the efficiency of solar cells. Experimental results are presented which validate the theoretical discussion. Results of electron bombardment experiments on p on n and n on p solar cells are given which show the n on p cell structure to be approximately five times more resistant to damage by 2 mev and 700 kev electrons. Electron bombardment experiments on n on p cells fabricated at Transitron are presented which agree with the results obtained with the Signal Corps n on p cells. The fabrication of Transitron radiation resistant n on p solar cells is discussed and the process as developed thus far is given.

1-1134. INTERNATIONAL CONFERENCE ON THE USE OF SOLAR ENERGY, Tucson, Arizona, 31 Oct. and 1 Nov. 1955. TRANSACTIONS, VOL. I, THE AVAILABLE ENERGY MEASUREMENT OF THE RADIATION. Tucson, Univ. of Arizona Press, 1958. 135p.

The following papers are included in this volume: The Features of the Solar Spectrum as Imposed by the Physics of the Sun, by Richard N. Thomas; Transmission of Solar Energy through the Earth's Clear and Cloudy Atmosphere, by Sigmund Fritz; Principles and Problems in the Utilization of Solar Energy, by Farrington Daniels; Smithsonian Contributions to Solar Radiation Measurement, by C. G. Abbot; An Apparatus for the Continuous Measurement of Solar and Sky Radiation in Various Spectral Regions, by H. Stratmann; An Automatic Printing and Totalizing Device for Solar Radiation Measurements, by A. Richard Kassander, Jr., and Lyle L. Knowles; On the Principles of Solar Radiation Measuring Instruments, by W. Morikofer; Methods for the Open-Air Measurement of Caloric Radiation, by W. Morikofer; The Ratio of Ultraviolet to Total Solar Radiation in Phoenix, by C. R. Cryl; Solar Energy Distribution in Visible and Infrared, by A. Keith Pierce; Indirect Measurement of Solar Energy Variations in the Extreme Ultraviolet and X-Ray Region, by Walter Orr Roberts; the Observation of the Infrared Solar Spectrum at High Altitudes, by M. V. Migeotte; Observed and Computed Radiation from

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First to Fourth Contact during a Total Solar Eclipse, by Lyman J. Briggs; Some Problems of Measuring Solar Radiation in the Artic, by R. W. Gerdel; Opto-Graphic Computation of Insolation-Duration and Insolation-Energy, by Friedrich Tonne; Sky Radiation, Its Importance in Solar Energy Problems, by A. J. Drummond; and The Intensity of Solar Radiation in Southern Africa, by A. E. H. Bleksley.

1-1135. INTERNATIONAL CONFERENCE ON THE USE OF SOLAR ENERGY, Tucson, Arizona, 31 Oct. and 1 Nov. 1955. TRANSACTIONS, VOL. 2, THERMAL PROCESSES; Pt. 1, Sect. A, Flat-Plate Collectors. Tucson, Univ. of Arizona Press, 1958. 145p.

The following papers are included in this volume: Solar Energy Collector Design, by H. Tabor; Selective Radiation: I. Wavelength Discrimination II. Wave-Front Discrimination, by H. Tabor; Selective Spectral Characteristics as an Important Factor in the Efficiency of Solar Collectors, by J. T. Gier and R. V. Dunkle; Measurement of Spectral Sensitivity in the Infrared, by Carl P. Tingwaldt; A Solar Radiation Apparatus, by Richard W. Crain, Sr., Richard W. Crain, Jr., Gordon A. Vincent, and Bradley O. Reese; Evaluation of Flat-Plate Solar-Collector Performance, by H. C. Hottel and Austin Whillier; Solar Collector Studies at the University of Minnesota, by J. L. Threlkeld and R. C. Jordan; Application of Thermal Circuit Analysis to Collector Design, by G. V. Parmelee; The Prospects for Various Uses for Solar Reflectors as a Means of Environmental Control of Microclimates in Agriculture, by Basil M. Bensin; Remarks on the Use of Direct-Beam Radiation in Architecture and Agriculture, by F. A. Brooks.

1-1136. INTERNATIONAL CONFERENCE ON THE USE OF SOLAR ENERGY, Tucson, Arizona, 31 Oct. and 1 Nov. 1955. TRANSACTIONS, VOL. 2, THERMAL PROCESSES; Pt. 1, Sect. B, High-Temperature Solar Furnaces Solar Power. Tucson, Univ. of Arizona Press, 1958. 265p.

The following papers are included in this volume: High-Temperature Furnaces: Traitements à Haute Temperature au Moyen de Fours Centrifuges Chauffes par L'Energies Solaire, by F. Trombe and M. Foex; High Intensity Carbon ARC Sources for Thermal Radiation Studies, by C. P. Butler; The Importance of Accurate Temperature Measurements in Work with Solar Furnaces, by William M. Conn; The Operation and Use of a Lens-Type Solar Furnace, by P. Duwez, T. E. Tietz, E. Loh, and N. K. Hiester; A Guiding System for Solar Furnaces, by T. S. Laszlo, W. F. de Dufour, and J. Erdell; Construction of Solar Furnace, by T. Hisada. Solar Power: Solar Power from Reflectors, by C. G. Abbot; A Steam Engine Using a Mixture of Vapors from Non-Miscible Fluids as a Solar Engine with Flat-Plate Collectors, by Luigi d'Amelio; The Solar-Powered Thermopump, by C. D. Mac Cracken; Hydrocarbon Fuels via Photosynthesis: An Evaluation of the Processes and their economics, by R. L. Meier.

1-1137. INTERNATIONAL CONFERENCE ON THE USE OF SOLAR ENERGY, Tucson, Arizona, 31 Oct. and 1 Nov. 1955. TRANSACTIONS, VOL. III, THERMAL PROCESSES, Pt. 2, SOLAR HOUSE HEATING, SOLAR WATER HEATING, SOLAR STOVES, AND SOLAR DISTILLATION. Tucson, Univ. of Arizona Press, 1958. 169p.

The following papers are included in this volume: Solar House Heating: Circuit Analysis Applied to Solar House-Heating, by Harry Buchberg; Solar Heat Pump Systems, by R. C. Jordan and J. L. Threlkeld; How to Combine Solar Energy, Nocturnal Radiational Cooling, Radiant Panel System of Heating and Cooling, and Heat Pump to Make a Complete Year-Round Air-Conditioning System, by M. Yanagimachi. Solar Water Heating: Les Insolateurs à Bas Potentiel, by H. Masson; Present Status of Solar Water Heaters in Japan, by I. Tanishita. Solar Stoves: Reflective Solar Cooker Designs, by J. A. Duffie; Solar Stoves, by Maria Telkes. Solar Distillation: Development of Plastic Solar Stills for Use in the Large-Scale, Low-Cost Demineralization of Saline Waters by Solar Evaporation, by Risto Lappala and Johan Bjorksten; Some Experiments on Solar Distillation of Sea Water in Cyprus during the Summers of 1954 and 1955, by R. Fitzmaurice and A. C. Seligman; Practical Possibilities for the Use of Solar Distillation in Under-Developed Arid Countries, by Cyril Gomella; Efficiency of Various Types of

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Solar Stills, by J. Savornin; Recovering Water-Vapor from the Atmosphere, by G. LeJeune and J. Savornin; Avoiding Crystallization in Solar Stills, by G. LeJeune; Improved Solar Stills, by Maria Telkes; Solar Distillation in Australia, by Bruce W. Wilson; Solar Distillation, by Everett D. Howe.

1-1138. INTERNATIONAL CONFERENCE ON THE USE OF SOLAR ENERGY, Tucson, Arizona, 31 Oct. and 1 Nov. 1955. TRANSACTIONS, VOL. IV, PHOTOCHEMICAL PROCESSES. Tucson, Univ. of Arizona Press, 1958. 187p.

The following papers are included in this volume: Algal Growth--Processes and Products, by Jack Myers; Nutritional Requirements and Yields of Algae in Mass Culture, by Robert W. Krauss and Alston W. Specht; Photosynthetic Nitrogen Fixation by Blue-Green Algae, by M. B. Allen; Effect of Variation of Day-Length, Day- and Night-Temperatures, and Intensity of Daylight upon the Growth of Chlorella, by H. Tamiya, T. Sasa, T. Nihei, and S. Ishibashi; The Yield of Sunlight Conversion by Chlorelia, by B. Kok; Studies on the Deep Mass Culture of Algae in Israel, by A. M. Mayer, A. Eisenberg, and M. Evanari; On the Protein Quality and the Liver Necrosis Preventive Factor of Unicellular Algae, by Hermann Fink; Algal Culture in Sewage, by Maria Elisabeth Meffert; Utilization of Solar Energy for Waste Reclamation, by Harold B. Gotaas and William J. Oswald; The Merits of Higher Plants as Storers of Solar Energy, by Norman W. Pirie; The World's Principal Food Plants as Converters of Solar Energy, by Paul C. Mangelsdorf; The Chloroplast as the Photoreceptive Mechanism in Photosynthesis, by J. B. Thomas; Energy Transfer within the Chloroplast, by L. N. M. Duysens; The Photochemistry of Chlorophyll in Vitro, by Robert Livingston; The Evolution of

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Organic Photochemistry on Earth, by Hans Gaffron; The Use of Solar Energy in the Preparation of Organic Compounds, with Special Reference to the Photo-Chemistry of Aldehydes and Ketones, by Alexander Schoenberg; Some Possibilities for Solar Energy Utilization by Means of the Photovoltaic Effect, by Scott Anderson; Photochemical Conversion Reactions and the Storage of Energy as Hydrogen, by Rudolph J. Marcus; The Photochemical Storage of Energy, by Eugene I. Rabinowitch.

1-1139. INTERNATIONAL CONFERENCE ON THE USE OF SOLAR ENERGY, Tucson, Arizona, 31 Oct. and 1 Nov. 1955. TRANSACTIONS, VOL. V, ELECTRICAL PROCESSES. Tucson, Univ. of Arizona Press, 1958. 132p.

The following papers are included in this volume: Materials for Thermoelectric Generators, by Maria Telkes; Mechanical Construction and Thermal Characteristics of Solar Operated Thermoelectric Generators, by Harold Heywood; The Efficiency of Solar Thermoelectric Generators Composed of Semiconductors, by T. Momota and Y. Matsukura; The Technical and Economic Limitations of Low-Voltage Generators for the Production of Large Amounts of Electric Power, by Marcus O'Day; A Thermoelectric Effect with Powered Metallic Oxides, by M. Perrot, G. Peri, and J. Robert; Photogalvanic Cells, by K. M. Sancier; The Theory of Energy Conversion in p-n Junctions, by Robert L. Cummerow; Theoretical Considerations Governing the Choice of the Optimum Semiconductor for Photovoltaic Solar Energy Conversion, by Joseph J. Loferski; The Silicon p-n Junction Solar Energy Converter, by M. B. Prince; The Photovoltaic Effect of Cadmium Sulfide Crystals, by D. C. Reynolds; Some Observations from a Year of Silicon Solar Battery Testing, by D. M. Chapin; Areas for Improvement in the Semiconductor Solar Energy Converter, by Edmund D. Jackson; Military Considerations for a Photovoltaic Solar Energy Converter, by William R. Cherry.

1-1140. MATHEMATICAL MODEL OF FACTORS AFFECTING SOLAR ENERGY COLLECTOR EFFICIENCY. Frederic E. Fuller. Electro-Optical Systems, Inc., Pasadena, Calif., EOS Rept. no. 480, Final; WADD TR 60-907. 30 Dec. 1960. 227p. illus. Contract: AF 33(616)-7316. 18 refs. A61-10122.

The purpose of these investigations is to establish bases and methods for the performance analysis of a solar energy collector system. The collector system considered consists of a concentrator mirror substantially paraboloidal in form and a cavity type absorber. The first section of this report lists the equations from which the net heat transfer to the inner surface of the absorber cavity may be computed. The method for calculating the temperature distribution on the inner surface is also presented. The equations are written in terms of quantities which are discussed and derived in Sections 2 and 3. Thus, Section 1 contains the equations from which may be calculated the heat input to a heat engine cycle having the absorber as the boiler. Section 2 contains a detailed analysis of the geometric optics of concentrator mirrors. Expressions are derived for the geometrical relationships of the source, concentrator, and absorber. The cases of a primary mirror and a secondary mirror used in conjunction with the primary mirror are discussed. The equations have been specialized for the case of the sun as source; nevertheless, the case of the general source is fully discussed. For any point in

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the focal region, the intensity vector may be computed from the methods presented in Section 2. The special cases of 1) perfect paraboloidal mirrors perfectly placed 2) imperfect paraboloidal mirrors imperfectly placed and 3) paraboloidal mirrors with small random errors are developed so that the intensity vector may be computed. The geometric optics of radiation cavities are presented in Section 3. The total emitted energy incident upon, reflected from, and emitted from any point on the inner surface of the cavity may be computed. In similar fashion, the total solar energy incident upon, and reflected from any point on cavity inner surface may also be computed. From these quantities, the net heat transfer to the cavity wall and the temperature distribution may be calculated. The heat transfer to the surface depends strongly upon the value and nature of the surface emissivity, absorptivity, and reflectivity. Because of their importance, a discussion of these quantities is included. Detailed plans are presented in Section 4 for the development of computing machine programs for the collector system performance computations. Although the procedures in the programs are described explicitly, extensive work by a programmer and a subject matter specialist is required for their realization. Section 5 considers an elastic solid in the shape of a paraboloidal shell of revolution which is composed of two perfectly bonded layers of materials of different elastic and thermal properties. A set

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of equations for the determination of stresses and displacements in the shell due to thermal loads is derived. The effects of the environment on the collector system are discussed in Section 6. The influence of the following phenomena is indicated: 1) Loss of mass due to sublimation; 2) Electromagnetic radiation; 3) Erosion caused by bombardment of low energy atomic and molecular particles; and 4) Meteoroid bombardment. As a result of working on this report, several fields of investigation, logical extensions to the analysis presented herein and worthy of further study, are presented in Section 7.

1-1141. SOLAR ENERGY TECHNOLOGY: 1954-1959. T. Brimelow. Special Subject List No. 34. The Library Association Chaucer House, Malet Place, London. 1961. 32p. Pam 61-439.

This bibliography lists 327 references to the published literature on solar energy for the period 1954-59. Topics listed are general applications, aerospace applications, air conditioning, automotive engineering, biological sciences, electrical conversion, furnaces, heating, radio, refrigeration and water treatment.

SECTION G - THERMIONIC DEVICES

1-1142. A CESIUM VAPOR THERMIONIC CONVERTER USING A THORIUM DISPENSER CATHODE. J. M. Houston. General Electric Co. Research Lab., Schenectady, N. Y. Scientific report no. 1. May 1960. AF CRL 253. Contract: AF 19(604)-5472. 11p. illus. A61-7369.

A thermionic heat-to-electricity converter was tested which consisted of 13.3 cm^2 thorium dispenser cathode spaced 1 mm from a copper or fernico anode. Current-voltage characteristics and power output were taken as a function of cathode temperature and cesium pressure. At a cathode temperature of approximately 2200°K, an anode temperature of 450°K, and a cesium pressure of 2×10^{-2} mm, a dc power output of 42 watts (30 amp at 1.41 volts) was delivered to a resistive load at an overall efficiency of 7%. The effect of anode temperature on converter power output was explored by recording a series of current-voltage plots at different anode temperatures. The power output went through a maximum at an optimum anode temperature where the anode work function was minimum (optimum Cs coverage). The changes in anode work-function were also observed by measuring the thermionic emission from the anode. The effect of an applied axial magnetic field on the converter output was explored. At low Cs pressures, a field of 20 gauss reduced power output to 2/3 of its zero-field value. At high Cs pressures, a magnetic field of 80 gauss had no measurable effect on converter output.

1-1143. DESIGN STUDY FOR ADVANCED SOLAR THERMIONIC POWER SYSTEMS--ITEM II--PART II; CLOSE-SPACED VACUUM THERMIONIC GENERATOR. Thompson Ramo Wooldridge Inc. and Thermo Electron Engineering Corp., WADD TR 60-698, Part II. Sept. 1960. 91p. illus. Contract: AF 33(616)-7411, Proj. no. 0(3-3145), Task no. 60962. A61-7036, pt. 2.

This report describes the results of a design study on close-spaced vacuum thermionic converters and gives general description of the unit and the assembly procedures of the cell and of the entire unit, establishing the design and test specifications for a laboratory test model close-spaced vacuum thermionic converter designated Model TRW-1B. This unit is rated at 28 volts, 250 watts electrical power output. The design involves the construction of 98 cells with 1-$in.^2$ emitters. Groups of seven cells will be mounted on each of 14 trays, which form the sides of a polygon. Electrically, the unit consists of two parallel banks of 49 series connected cells. Based on Langmuir's space-charge solution, the power output and ideal efficiency of the unit are first evaluated. It is found that 98 cells, each with an emitting area of 6.45 cm^2, operating at a temperature of 1500°K will give a total power output of 290 watts. By connecting half the cells in series, an output voltage of 27.5 volts is obtained. The ideal efficiency is found to be 8%. Subsequently, the additional heat losses due to conduction through and

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radiation by the structure of the unit are evaluated, and the over-all efficiency is found to be 6.4%. From the power output and the efficiency, the necessary radiator surface at 900° K is estimated, and it is proved necessary to extend the surface of the trays by fins to obtain sufficient area to reject the heat at 900° K. Finally, the temperature drop along the cell and the fins is evaluated and is shown to be within acceptable limits. The operating temperature of the unit is 1500° K. The necessary heat input is 4000 watts. This heat input is provided by radiation from a tantalum cylinder which is heated to 2000° K by electron bombardment. This method of electrical heating is considered to be superior to resistance heating mainly because of structural problems at the high operating temperatures of the source. Further, a preliminary design of the voltage regulator, a description of experimental test procedures, some experimental results, and the design of the vacuum unit are considered. Finally, the design specifications of the various parts of the unit are summarized.

1-1144. TESTS OF A CESIUM THERMIONIC CONVERTER DESIGNED TO UTILIZE SOLAR ENERGY IN OUTER SPACE. V. C. Wilson and Jackson Lawrence. General Electric Co. Research Lab., Schenectady, N. Y. Scientific Report no. 3. Aug. 1960. 22p. illus. Contract: AF 19(604)-5472. AF CRL 281. A61-7371.

A thermionic converter is a static high temperature heat engine that generates low voltage dc electricity. In operating a heat engine, removing the unused heat is as important as supplying heat. Radiation is the only means for removing heat in outer space. Since the cold temperature of a thermionic converter may be as high as 900° K, and heat radiation is proportional to the fourth power of the temperature, it should be possible to use a thermionic converter with a comparatively small and light weight radiator. Therefore, a program was initiated to work out the design of a thermionic converter and radiator that might be integrated into an electric power generating system utilizing solar energy in outer space. A cesium thermionic converter with an integral radiator for solar application has been designed and tested. Design, construction and processing techniques are discussed. Performance data under various operating conditions are given including a maximum output power at 1800° C of 85 watts with 15% efficiency. The electric generator and reject heat radiator weighs 7.5 lbs/kw of output electricity.

1-1145. THERMIONIC GENERATORS - MATERIALS ARE THE KEY TO THEIR DEVELOPMENT. John Coltman. Westinghouse Engineer, vol. 20, no. 4, July 1960, p. 102-04.

Thermionic generators produce electrical power by using electrons emitted from a surface heated to a high temperature. Although they are still in early stages of development, thermionic devices offer promise as a power source where compactness, light weight, simplicity, and high efficiency are required. Materials must be found which combine a high heat of vaporization with a low work function; they must be capable of operation for long periods at temperatures up to 4500° C. The operating principles are considered quantitatively for a number of materials. The efficiency of conversion depends on such properties as the work function, electron emission constants and radiant emissivity, and the operating temperature.

1-1146. VACUUM THERMIONIC ENERGY CONVERTER. J. E. Beggs. General Electric Co. Research Lab., Schenectady N. Y. Scientific report no. 2. July 1960. Contract: AF 19-(604)-5472. A61-7370.

The utilization of materials and techniques employed in building electron tubes for use at high ambient temperatures and in high density nuclear fluxes provide a basis for the construction of a high vacuum thermionic energy converter. Heat is applied to the external surface of one electrode of the converter. The interior surface of this hot electrode operates in a vacuum and is coated so that it is capable of emitting copious numbers of electrons. The other electrode of the converter has a coating on its interior surface that can provide a low anode work function so as to increase the energy available to an external load. The output and efficiency of a vacuum thermionic energy converter improve as the emitter is heated hotter and as the electrodes are spaced more closely. At an emitter temperature of 1100° C, an output of 1 watt/cm^2 and an efficiency of 4.5% have been attained. In practical applications heating can be accomplished by the use of chemical fuel, solar radiation, or nuclear energy. While it has been demonstrated that a practical thermionic converter can be built using existing vacuum tube materials and techniques, additional research and development work is needed to realize or approach the high outputs and efficiencies that are theoretically possible. Research

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studies in the basic physics of thermionic work function could produce materials that might increase considerably the useful output voltage and current. For use at the elevated temperatures indicated for a vacuum converter having high output and efficiency, additional work is needed to find materials that have low gas evolution, high strength and resistance to oxidation.

SECTION H - THERMOELECTRIC MATERIALS

1-1147. THERMOELECTRICITY ABSTRACTS. Naval Research Lab., Washington, D. C. May 1959. 104p. A61-4192.

1-1148. THERMOELECTRICITY ABSTRACTS. Naval Research Lab., Washington, D. C. Aug. 1959. 74p. A61-4244.

1-1149. FUTURE POWER SOURCES: THERMOELECTRIC GENERATORS--APPLYING THE SEEBECK EFFECT TO POWER GENERATION. Stephen J. Angello. Westinghouse Engineer, vol. 20, no. 4, July 1960, p. 98-101.

Thermoelectric power is generated when one end of a metal segment is heated, producing a voltage difference between the hot and cold ends. Recently the efficiency and size of thermoelectric generators has been raised to levels suitable for practical power generation. Advantages of thermoelectric devices are their ruggedness, compactness, and lack of moving parts. In space applications the gyroscopic effects of rotating devices create troubles with guidance and stability. An important factor in the growth of thermoelectric technology is the ability to adjust the number of free electrons in semiconductor materials; the optimum density is about 10^{19} free electrons per cubic centimeter, which is an acceptable compromise between high voltage and high electric conductivity. It affords Seebeck voltages of about 175 mv/° C. Zinc antimony, lead telluride, bismuth telluride, and germanium telluride have acceptable efficiencies. Currently, 15 watts /lb of weight is feasible. Present efficiencies are about 6%, but within five years, generators of about 20% efficiencies are expected.

1-1150. OPTIMIZATION OF THERMOELECTRIC ENERGY CONVERTERS. Bimonthly Progress Report no. 2, 15 June-14 Aug. 1960. General Electric Co., Aircraft Accessory Turbine Dept., Lynn, Mass. 49p. illus. Contract NObs-78403. AD 260 368. A61-10321.

The activities of all five aspects of this program during the second two-month period of the contract are described in this report. A preliminary analysis of the first thermal system to be investigated has been nearly completed. This system consists of saturated steam at 533° K (500° F), a thermoelectric generator utilizing thermoelectric materials representative of the present state-of-the-art, and a sea-water heat sink at 291° K (65° F). Leakage of heat through the thermal insulation has been taken into account in the calculations, as have other factors, such as contact resistance, the dimensions of the container of the generator, and the dimensions of the conductors connecting the individual arms. The effects of variation of these parameters on the power output per unit weight, volume, and area of the system are graphically portrayed in a manner useful to the design engineer. This report contains the results for cooling by free convection of the sea-water coolant, together with preliminary results for the forced-convection case. A magnesia-titania ceramic body has been tested and found to be a material suitable as a high-temperature encapsulating medium in conjunction with iron

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end-caps. Because its coefficient of thermal expansion more closely approximates that of iron than does forsterite, the new materials may permit reduction of the wall-thickness of tubing used for encapsulation of thermoelectric materials, effecting a marked diminution in thermal losses through the encapsulant. Improvements in sealing technology include the construction of an improved sealing apparatus and its use for closing an easily-filled cell that will facilitate the study of thermoelectric properties of encapsulated materials. Encapsulation of p-type lead telluride has successfully been accomplished, although further study is required in order to make the procedure completely reliable. Preliminary batches of Mg_3Sb_2 have been prepared in inert-atmosphere furnace designed for operation at temperature up to 1400° C. It appears that problems arising from reaction of the constitutents with the container can be solved by use of a molybdenum vessel with a split-crucible design. A versatile zone-refining apparatus for purification of lithium has been constructed and tested. Infrared reflectance measurements on a specimen of CrSb indicate that its absorption edge lies in the 14-micron range, suggesting a lower band-gap energy than initially expected. If this conclusion is verified by thermal measurements, it will be necessary to alloy the compound with large-gap materials in order to produce an alloy

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with optimum properties at elevated temperatures. Leakage in a tantalum-lined iron bomb precluded the successful preparation of samples of Ca_2Pb and Ca_2Sn. A welded vessel, made entirely of tantalum, has been designed in an effort to solve the problems arising from the volatility and corrosive nature of the calcium.

1-1151. THE DYNAMIC BEHAVIOR OF THERMOELECTRIC DEVICES. Paul E. Gray. Massachusetts Inst. of Tech., Cambridge. Electronic Systems Lab., Scientific Report no. 3; AFCRC-TN-60-580. 1 June 1960. 135p. illus. Contract: AF 19(604)-4153. 17 refs. AD 242 178. A61-10334.

The principal theme of this study has been the investigation of the dynamic behavior of thermoelectric devices. In particular, those aspects of the dynamic behavior that are of interest in the control of simple thermoelectric heat pumps and generators have been studied. The requirements for control led to the consideration of those dynamic relationships that exist among the incremental components of the several variables that define the state of the system. These relationships were obtained from the frequency-domain solution of a set of linear partial differential equations that were subject to linear boundary conditions, and were expressed in the form of frequency-domain transfer functions. The small-signal transfer functions that were calculated for both the heat pump and the generator are summarized. In these equations, $\Phi_0(s)$ and $\Phi_2(s)$ are the transforms of the incremental junction temperatures; $\mathcal{P}_{os}(s)$ is the transform of the source portion of the incremental heat rate at the cold junctions for the heat pump and at the hot junctions for the generator; $\mathcal{I}(s)$ is the transform of the incremental electric current; and $\mathcal{R}(s)$ and $\mathcal{V}_L(s)$ are the transforms of the incremental load resistance and load back-emf for the generator. For both the generator and (cont.)

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the heat pump, techniques that allow the calculation of the natural frequencies of the system and that permit evaluation of the response of the system to sinusoidal and other Fourier-transformable input functions have been presented. Consequently, the transfer functions can be used to calculate the frequency response and singularity-function response of the system without excessive difficulty. An experiment has been conducted in order to verify the model and the incremental analysis. Measurements of both the incremental step response and the incremental frequency response of a heat pump for changes in the control current have been made. The time-domain measurements are in very good agreement with the calculated dynamic behavior of the system and indicate that the model and the analysis are sufficiently accurate in their description of the device for most purposes.

1-1152. THEORETICAL AND EXPERIMENTAL RESEARCH IN THERMOELECTRICITY. Masachusetts Inst. of Tech., Cambridge. Dept. of Electrical Engineering, Scientific Report no. 1; AFCRC-TN-60-125. 31 Dec. 1959. 150p. illus. Contract: AF 19(604)-4153. A61-8290.

The initial problem, and probably the most difficult one, was to decide which materials should be investigated from the standpoint of thermoelectric effects. A few materials of known promise for thermoelectric application have been selected and work has proceeded on these. Once the materials have been selected, the problem of producing suitable specimens of the materials must be solved. Section I of this report deals with the progress that has been made in this respect. Techniques and equipment for growing single crystals of Bi_2Te_3 are described. Results of various techniques of processing polycrystalline material suitable for device applications are also presented. Although the preparation of Bi_2Te_3 is now in a fairly advanced state, it should be noted that, when other materials are considered, a substantial modification of technique may be necessary. This is well illustrated in the case of WTe_2 reported in Section III. The preparation of HgTe-CdTe alloys is included in Section III with a general discussion of measurements on this material. Section II deals with measuring equipment which has been developed in order to measure those parameters which characterize the

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thermoelectric material (resistivity, thermoelectric power thermal conductivity, Seebeck coefficient, electrical conductivity). Much of this equipment is intended to be used for relatively rapid evaluation of thermoelectric materials either as an evaluation of the crystal preparation process or to determine the suitability of the material for thermoelectric devices. The instrumentation is well developed and should not require modification for use with other materials. Section III is concerned with detailed measurements other than routine evaluation of material. As such, it includes investigation of both the dependence of thermoelectric parameters on detailed microscopic processes and the actual behavior of thermoelectric devices. This effort involves additional equipment and is closely tied to the materials preparation and evaluation and to the analysis and theory of Section IV. This type of work will continue with the present materials, as well as with new materials, and considers the following topics: analog circuits of thermoelectric generators, dynamic behavior of thermoelectric devices, multistage thermoelectric refrigeration, cascade arrangement of thermoelectric generators and investigation of Nernst effect.

1-1153. THERMOPILE GENERATOR FEASIBILITY STUDY. PART II--MATERIALS INVESTIGATIONS. J. H. Bredt, ed. General Electric Co., Schenectady, N. Y., WADD TR 60-22, Pt. II. Aug. 1960. 323p. illus. Contract: AF 33(616)-5281, Proj. no. 3145, Task no. 60199. A61-9730, pt. 2.

This is Part II of a report on a research and development study to determine means of employing thermopile generators as sources of electrical power in future air and space weapon systems. The major areas of work involved are materials development, junction fabrication and test, thermoelectric generator applications studies, and thermoelectric generator design. This part contains the details of the work on materials development. It consists of the 17 appendices listed below by title:

Appendix A - Metallic Materials for Thermopile Generators, by John P. Denny.
Appendix B - Power Per Unit Volume, by John P. Denny.
Appendix C - Thermoelectric Power of Metallic Alloys and Transition Metal Hydrides, by John P. Denny.
Appendix D - Thermoelectric Power of Metallic Alloys and Transition Metal Hydrides, by John P. Denny.

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Appendix E - The Feasibility of Using Refractory Materials for Thermoelectric Generator (TEG) Elements, by Hans J. Borchardt.
Appendix F - Seebeck Voltage and Resistivity of "Refractory Metals", by John R. Gambino.
Appendix G - Thermoelectric Power of Refractory Borides, Carbides, Nitrides, and Silicides, by John R. Gambino.
Appendix H - Some Preliminary Results in the Study of Oxide Thermoelectric Generator Materials, by John R. Gambino.
Appendix I - Seebeck Voltage and Resistivity of Compositions Based on Chromium Oxide, by John R. Gambino.
Appendix J - A Study of Oxides for Thermoelectric Generator Applications, by John R. Gambino.
Appendix K - Summary of Measurements of Resistivity and Seebeck Coefficient of Ferrites and Titanates at Temperatures up to 1000°K, by Philipp H. Klein.
Appendix L - Summary of Thermoelectric Investigations of Encapsulated Intermetallic and Liquid Semiconductors, by E. Fischer-Colbrie.

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Appendix M - Growth of Single Crystals of Transition Metal Oxides and Measurement of their Thermal Conductivity, by F. H. Horn, R. Newman, and G. A. Slack.

Appendix O - Thermal Conductivity Studies with the Powell Method, by A. I. Dahl.

Appendix P - The Powell Method of Measuring the Thermal Conductivity of Solids, by A. I. Dahl.

Appendix Q - Analysis of Radiation Heat Losses in Measurement Apparatus, by S. B. Dunham.

Appendix R - Measurements - Z Meter, by F. A. Ludewig.

II. MATERIALS

SECTION A - GENERAL

1-1154. A BENCH SCALE METHOD FOR DETERMINING PERFORMANCE CHARACTERISTICS OF LUBRICANTS IN AN OXIDATIVE ENVIRONMENT AT HIGH TEMPERATURES. Samuel B. Schexnailder. Wright Air Development Center. Materials Central. Wright-Patterson AFB, Ohio, WADD TR 60-794. Dec. 1960 31p. illus. Proj. no. 3044, Task no. 73314. A61-10125.

A method for studying physical and chemical characteristics of experimental fluids when subjected to varying environmental conditions has been devised by the Nonmetallic Materials Laboratory in cooperation with industry. In order to demonstrate that results obtained would give an accurate prediction of large scale lubricant applications under the exact same environmental conditions, the temperatures, air flow rates and metals used were those encountered in actual +425°F jet engine operation. Results of the work described in this report have demonstrated excellent correlation between the "bench scale method" and the full scale gas-turbine engine application at 425°F bulk oil temperatures. This correlation confirmed the Nonmetallic Materials Laboratory's belief that small scale methods and experimental fluid in order to determine their probable full scale potential under any given set of environmental conditions. This method will be used in future research studies of new high temperature fluid candidates such as the poly-phenyl ethers,

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silphenylenes, pyrazines and fluorinated aromatics. A large background of physical and chemical data can be built up in this manner on these materials for use in future Air Force Weapons Systems.

1-1155. DEVELOPMENT OF GREASE LUBRICANTS FOR HIGH TEMPERATURE BALL AND ROLLER BEARINGS OF ELECTRICAL EQUIPMENT. A. C. Borg, K. R. Bunting, et al. Standard Oil Co. (Indiana), Whiting, Indiana, WADD TR 60-557, Pt. I. Oct. 1960, 54p. Contract: AF 33(616)-6584, Proj. no. 3044, Task no. 73310. A61-10117, pt. 1.

The objective of this contract is the development of grease systems for use in ball and roller bearings of electrical equipment over an ultimate temperature range of -65°F to +900°F. The current program is aimed at the development of a -40°F to +700°F grease. The high-temperature performance is the more difficult requirement to satisfy and efforts were concentrated on developing and screening fluids, thickeners and greases at 600°F. 600°F was chosen because long time performance at this temperature is required by the contract and it was close to the limit of significantly long performance of available greases and test equipment at the beginning of the contract. Equipment was built or obtained for running loaded bearing tests, dropping points, evaporations, and roll stabilities at temperatures up to 900°F. Several types of bearings, said to be better for high temperature use than the MRC 204 S-17 bearings used in this period, were received at the end of this reporting period, but no tests have yet been run on them. Fluids and thickeners, believed to be potentially useful in -40°F to 700°F greases, were synthesized or obtained

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from outside sources and screened in bench tests for adequately high thermal stability and low volatility. Thickeners were also screened for thickening ability over the temperature range. Materials that appeared promising after screening were made into greases and bearing tested. Fluids were thickened with the best high-temperature thickener available, and thickeners were dispersed in the best high-temperature fluid to obtain the greases for these tests. Most bearing tests were run at 600°F, under modified CRC L-35 conditions, on Pope-Texas type spindles. Under these conditions, the best of the currently available greases, methylphenyl silicones, thickened with one of several high-melting organic thickeners ran for about 55 hours. Greases made with several experimental silicone fluids gave results that ranged from slightly worse to significantly better than those obtained with the best available greases. The best results were obtained with DC-QF-6-7024 Silicone Fluid which ran from 100 to 400+ hours in various tests. Failures were due to the instability of the silicone fluids. The best phenoxyphenyl ether and chain-type polyphenyl greases ran as long as the best of the currently available greases. Failures were not due to fluid instability, but fluid volatility. Preparation of lower volatility fluids of these and related structures are under way. Surface treated silica, carbon black and glass fiber thickeners gave better results than the best of the currently used high-temperature thickeners.

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In addition, some promising initial results were obtained with high melting polymers, complex sulfonyls and sulfonamides, and some organic pigments. None of these thickener systems has been completely perfected and even better results are to be expected as they are further developed.

1-1156. LUBRICITY OF EXPERIMENTAL HIGH TEMPERATURE POWER TRANSMISSION FLUIDS. PART I. PUMP WEAR AT 275°F. Leslie R. Drane and R. J. Benzing. Wright Air Development Center. Materials Central. Wright-Patterson AFB, Ohio, WADD TR 60-583, Pt. I. Sept. 1960. 87p. illus. Proj. no. 8128, Task no. 73313. A61-10173, pt. 1.

The lubricity of several experimental high temperature power transmission fluids of widely varying chemical types was investigated. A New York air brake company pump was used at 275°F as a means of studying the wear behavior. Four-Ball wear tests also were run. The fluids consisted of a silicone-ester blend, an ether, and two disiloxanes. In general, these high temperature fluids gave comparable lubrication to that afforded by normal temperature petroleum fluids. In most cases the desired five hundred hours of operation were successfully completed. Such performance demonstrates the feasibility of the experimental fluids. No correlation could be obtained between the Four-Ball wear tests and the pump wear tests.

SECTION B - HIGH STRENGTH METALS

1-1157. AVAILABILITY AND MECHANICAL PROPERTIES OF HIGH-STRENGTH STEEL EXTRUSIONS. R. J. Fiorentino and A. M. Sabroff. Battelle Memorial Inst. Defense Metals Information Center, Columbus, Ohio, DMIC Rept. no. 138. 26 Oct. 1960. 60p. illus. Contract: AF 18(600)-1375. A61-10873.

Information on the availability and mechanical properties of high-strength steel extrusions is compiled. Six classifications of high-strength steels are considered. Typical current extrusion specifications are discussed, and illustrative mechanical properties are reported. Some attention is devoted to anticipated future consumer requirements.

1-1158. DEPARTMENT OF DEFENSE TITANIUM SHEET-ROLLING PROGRAM. H. R. Ogden. Battelle Memorial Inst. Defense Metals Information Center, Columbus, Ohio, DMIC Rept. 46H, Status Rept. no. 5. 1 June 1960. 74p. illus. Contract: AF 18(600)-1375. A61-6906.

This report summarizes the progress made on the Titanium Sheet-Rolling Program during the period from 1 January 1959 through December 1959. During this period, the production of the heat-treatable alloys has been completed by one producer and is nearing completion by the other two producers. Three new alloys have been added to the program--Ti-7Al-12Zr, Ti-8Al-1Mo-1V, and Ti-8Al-8Zr-1(Cb+Ta). These are designed to be weldable alpha alloys with high creep strength. Phase II, the development of design data, has been started, with testing well under way. This work is being done on production-aged material by Lockheed Aircraft Corporation, Marietta, Georgia. Two of the seven Phase III contractors have completed their programs, and evaluation is well along for the other five contractors. The two companies which conducted preliminary evaluations of three alloys chose Ti-4Al-3Mo-1V as the most promising alloy for fabrication of parts. All of the Phase III programs are scheduled for completion in 1960.

1-1159. DESIGN INFORMATION ON PH 15-7 Mo STAINLESS STEEL FOR AIRCRAFT AND MISSILES. R. J. Favor, O. L. Deel, and W. P. Achbach. Battelle Memorial Inst. Defense Metals Information Center, Columbus, Ohio, DMIC Rept. no. 135. 22 Aug. 1960. 38p. illus. Contract: AF 18(600)-1375. A61-10872.

This report is a summary of design information pertinent to the use of PH 15-7 Mo stainless steel in aircraft and missile applications. Welding problems are discussed briefly. Data on the elevated-temperature mechanical properties of this alloy have been collected and evaluated. The presentation and evaluation of these data are in accordance with procedures employed by the ANC-5 Committee.

1-1160. EVALUATION OF TITANIUM SHEET ALLOYS. Francis X. Drumm. Quarterly Progress Report no. 2, 1 Apr.-30 June 1958. Grumman Aircraft Engineering Corp., Bethpage, N. Y. Rept. no. R82053013.2. 30 July 1958. 32p. Contract: NO(as) 58-100C. A61-6464.

Progress during this second reporting period consisted of continuing the preliminary efforts necessary to the successful conclusion of this program plus initial work on four (4) sheets of Ti-4Al-3MO-1V. 1) Quality Analysis tests were performed on samples from each sheet. 2) Theoretical formability programs have been outlined in detail. 3) Manufacture and evaluation of test equipment was completed. 4) Manufacture of fatigue specimens was started. 5) A tentative design of the 3% horizontal stabilizer has been essentially completed.

1-1161. STATISTICAL ANALYSIS OF TENSILE PROPERTIES OF HEAT-TREATED Ti-4Al-3Mo-1V SHEET. H. R. Ogden, G. H. Beatty, and A. E. Mace. Battelle Memorial Inst. Defense Metals Information Center, Columbus, Ohio, DMIC Rept. no. 461. 16 Sept. 1960. 32p. illus. Contract: AF 18(600)-1375.

Some of the data developed through Phase I of the Titanium-Alloy Sheet-Rolling Program have been analyzed statistically to determine the magnitude of the variation in the tensile properties and the relation between these properties and some of the processing variables.

1-1162. TENSION, TORSION AND COLUMN PROPERTIES OF COMMERCIALLY PURE TITANIUM TUBING AT ROOM TEMPERATURE. Robert G. Henning. Wright Air Development Center. Materials Central. Wright-Patterson AFB, Ohio, WADD TN 60-201. Dec. 1960. 27p. illus. Proj. no. 7351. A61-11221.

Tensile, torsion and column properties were determined at room temperature on one heat of commercially pure titanium A 55 tubing in 1-in. and 3/8-in. outside diameters and varying wall thicknesses. Typical stress-strain diagrams are presented for torsion and tension. Torsion/tension and column/tension ratios vs diameter/wall thickness graphs are presented.

1-1163. TIME-TEMPERATURE-TRANSFORMATION DIAGRAMS OF THE TITANIUM SHEET-ROLLING-PROGRAM ALLOYS. L. E. Tanner. Illinois Inst. of Tech., Chicago. Armour Research Foundation, DMIC Rept. no. 46G. 19 Oct. 1959. 78p. illus. Contract: AF 18(600)-1375. 19 refs. A61-10552.

This investigation was conducted to determine the transformation kinetics of four commercial titanium-base alloys to assist in the planning of their heat treatment. These alloys were Ti-2.5Al-16V, Ti-4Al-3Mo-1V, Ti-6Al-4V, and B-120VCA (the all-β alloy Ti-13V-11Cr-3Al). The transformations investigated were those resulting from two types of heat-treatment cycles. The first was the classical sequence of a solution anneal followed by quenching directly to the lower reaction temperatures for aging. The second was based on commercial practice; the solution-annealed material was quenched to room temperature prior to being aged. Of the alloys mentioned above, the first three are the α-β type and were given a β solution anneal in the classical cycle and an α+β solution anneal in the commercial cycle. The last alloy, B-120 VCA, is solution treated in the β field in commercial practice and therefore was β solution annealed in both cases. Test samples were cut from sheet obtained from the producers. The effect of heat treatment on the samples was determined primarily by metallographic examination and measurements of hardness. Critical data were obtained by measurement of electrical

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resistivity, by X-ray diffraction, and by determining dynamic elastic modulus. Presented in this report are T T T diagrams for the four alloys; each diagram is documented with photomicrographs and hardness curves, as well as with pertinent data obtained by the other techniques.

1-1164. DEVELOPMENT OF NIOBIUM-BASE ALLOYS. Richard T. Begley. Westinghouse Electric Corp. Aviation Gas Turbine Div., Kansas City, Mo., WADC TR 57-344. May 1958. 104p. illus. Contract: AF 33(616)-3316, Proj. no. 3105. 44 refs. AD 155 583. A61-9879.

The flow and fracture characteristics of commercial purity powder metallurgy niobium were investigated in the range 250 to -196°C. Niobium was found to undergo a ductile-brittle transition in the range -125 to -196°C, and the transition temperature range of niobium was found to be less affected by the presence of interstitial impurities than many other body-centered cubic metals. The creep-rupture properties of powder metallurgy niobium were investigated at 982 and 1093°C (1800 and 2000°F), and the 100-hr. rupture strength of commercial niobium in vacuum was determined to be significantly greater than unalloyed molybdenum. The creep-rupture results suggest that small quantities of gaseous contaminants may be responsible for the high strength of commercial niobium at elevated temperatures. The oxidation behavior of niobium was investigated in the temperature range 350 to 700°C. At the higher temperatures, oxidation followed a linear rate law. Between 500 and 625°C, the rate of oxidation was found to be nearly independent of temperature. Oxygen and nitrogen contamination of welding atmospheres was studied

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to determine its effect on the weld properties of niobium. Nitrogen was established to be very detrimental to the mechanical properties of niobium welds. High-purity niobium, having a hardness of less than 60 VPN, was produced by cage-zone refining techniques.

1-1165. DEVELOPMENT OF NIOBIUM-BASE ALLOYS. Richard T. Begley. Westinghouse Electric Corp. Aviation Gas Turbine Div., Kansas City, Mo., WADC TR 57-344, Pt. II. Mar. 1959. 180p. illus. Contract: AF 33(616)-3316, Proj. no. 7351. 98 refs. AD 210 258. A61-9879, pt. 2.

Flow and fracture studies indicate that the ductile to brittle transition of niobium is little affected by oxygen content in the range 0.01 to 0.1% 0_2. The impact transition range of electron-beam melted niobium was found to be considerably below that of powder metallurgy niobium of somewhat higher oxygen concentration. Strain-hardening and strain aging in niobium were studied. An activation energy of 27, 100 cal/mol was determined for strain aging in niobium. The recrystallization behavior of electron-beam melted niobium was studied in detail. Creep-rupture data were obtained on electron-beam melted niobium at (871°C) 1600°F and (982°C) 1800°F. The electron-beam material had much lower rupture strength than powder metallurgy niobium containing 0.6% Zr tested previously. The effect of temperature on the modulus of elasticity of niobium and tantalum was determined in the range 25°C to 900°C. Studies of the thermodynamics of niobium oxides and the kinetics of Nb-water vapor reaction were carried out. The thermodynamic functions obtained in this study for the formation of Nb_2O_5 from Nb_2O_4 are in excellent agreement with calculated values. A selection of the most promising

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weldable niobium-base alloys was made on the basis of available physical and mechanical property data. Niobium of low oxygen and nitrogen content was produced by cage-zone and floating zone melting techniques. Evaluation of material prepared by electron-beam melting and vacuum arc melting was carried out.

1-1166. THE FABRICATION OF MOLYBDENUM. AN ANNOTATED BIBLIOGRAPHY. Maureen A. Pearcy. Lockheed Aircraft Corp. Missiles Systems Div., Sunnyvale, Calif., Special Bibliography SB-60-41. Dec. 1960. 48p. AD 252 206. A61-7094.

This bibliography presents a survey of recent literature on the fabrication of molybdenum and molybdenum alloys, particularly those alloys containing 0.5% titanium. The aspects of producibility that were covered include: 1) rolling and forming, 2) welding and brazing, 3) riveting, 4) shearing, and 5) spinning. The majority of literature cited has been published since 1958. The abstracts are arranged alphabetically by author.

1-1167. MELTING AND CASTING OF THE REFRACTORY METALS MOLYBDENUM, COLUMBIUM, TANTALUM, AND TUNGSTEN. W. H. Johnson. Battelle Memorial Inst. Defense Metals Information Center, Columbus, Ohio, DMIC Rept. no. 139. 18 Nov. 1960. 30p. illus. Contract: AF 18(600)-1375. 33 refs. A61-10874.

The technology of melting and casting refractory metals is considered from the standpoint of ingots and shaped castings. The production of ingots is more advanced than is the production of shaped castings. Molybdenum and columbium have been centrifugally cast with some success. Shaped castings of tantalum have been produced experimentally. No satisfactory method for the production of shaped tungsten castings is presently available. There is an indicated need for shaped castings of the refractory metals, and further development work appears to be justified. The cold-crucible induction furnace, presently under development for titanium, might be adapted for the refractory metals.

1-1168. PHYSICAL AND MECHANICAL PROPERTIES OF MOLYBDENUM AND THE Mo-0.5Ti ALLOY. Richard W. Douglass. Battelle Memorial Inst., Defense Metals Information Center, Columbus, Ohio, DMIC Memo 14. 10 Apr. 1959. 21p. illus. 18 refs. A61-6962.

The physical properties given for molybdenum are: density, specific heat, thermal conductivity, mean coefficient of thermal expansion, melting point at 4730°F, total optical emissivity from 1290 to 4710°F, spectral emissivity at 0.475μ and 0.665μ, electrical conductivity, thermal-neutron-absorption cross section, and Poisson's ratio. Mechanical properties including tensile, impact and fatigue data and creep and stress-rupture properties over a wide range of temperatures are also presented.

1-1169. STRAIN AGING OF REFRACTORY METALS. A. G. Imgram. Battelle Memorial Inst. Defense Metals Information Center, Columbus, Ohio, DMIC Rept. no. 134. 12 Aug. 1960. 62p. illus. Contract: AF 18(600)-1375. 47 refs. A61-10871.

The available data on strain-aging behavior of 12 refractory metals (V, Cb, Ta, Cr, Mo, W, Ru, Rh, Pd, Os, Ir, and Pt) are reviewed and interpreted in terms of dislocation models.

1-1170. TANTALUM AND TANTALUM ALLOYS. F. F. Schmidt. Battelle Memorial Inst. Defense Metals Information Center, Columbus, Ohio, DMIC Rept. no. 133. 25 July 1960. 328p. illus. Contract: AF 18(600)-1375. 287 refs. A61-10870.

A descriptive literature survey has been made covering physical properties, process metallurgy, binary and ternary alloy systems, chemical properties, and metallurgical properties of tantalum and tantalum alloys. The properties of tantalum are well reported; however, investigations concerned with the effects of interstitial and substitutional alloying elements on the properties of tantalum are limited. Tantalum has only moderate strength at room temperature; however, the elevated-temperature strength decreases slowly in comparison with that of many other metals. The low-ductile-to-brittle behavior, excellent fabricability, high melting point, and high solubility for interstitial and substitutional elements make tantalum an attractive candidate for use in high-temperature high-strength alloys. Refractory metals that exhibit brittle behavior at room temperature, such as molybdenum and tungsten, can be alloyed with tantalum to form tantalum-base alloys with a combination of high-temperature strength and low-temperature ductility not found in many metallic materials designed for ultra-high-temperature service.

SECTION D - BERYLLIUM

1-1171. A BIBLIOGRAPHY OF REPORT LITERATURE ON BERYLLIUM, JANUARY 1954-NOVEMBER 1959. Helen J. Chick. Los Alamos Scientific Lab., N. Mex., Rept. no. LAMS-2382. 10 Nov. 1959. 68p. Contract: W-7405-ENG. 36 with the U.S. Atomic Energy Commission. A61-8934.

The title describes the contents. Subject headings are: bibliographies and literature surveys; general data; physical and mechanical properties; metallurgy; fabrication; and structural applications.

1-1172. BERYLLIUM CRACK PROPAGATION AND EFFECTS OF SURFACE CONDITION. M. Jacobson, W. Jahsman, and C. Matthews. Third Quarterly Progress Report. Lockheed Aircraft Corp. Missiles Systems Div., Sunnyvale, Calif., Rept. no. LMSD-288005. 20 May 1959. 29p. illus. Contract: AF 33(616)-5978. A61-6465.

This is a progress report on a study contract. During the past quarter, the principal effort has been the preparation of machined specimens for testing and completion of test facilities. The extent of surface damage caused by grinding and milling operations was assessed by a taper-section technique. Examination showed that the worked layer was less than 0.001 in. thick; and, as evidenced by twinning, grinding produces more working than does milling. Work is underway on analysis of the dynamic stress distribution at the leading edge of a crack which arises suddenly in a plate under uniaxial tension. Tentative results are that the stress decreases slightly from the static value before it begins to increase indefinitely. This may explain partially the mechanism of a finite crack velocity.

1-1173. BERYLLIUM...SURVEY OF THE LITERATURE. K. D. Carroll. Lockheed Aircraft Corp., Missiles and Space Div. Sunnyvale, Calif. Rept. no. LMSD 288190, Special Biblio., Suppl. no. 2. Aug. 1960. 82p. AD 244 263. A61-7680, Suppl. 2.

The following annotated bibliography is the second quarterly supplement to BERYLLIUM: A SEARCH OF THE LITERATURE. Citations include those published, reviewed, or received during the period April-June 1960. Citations are arranged alphabetically by author or source under broad subject headings. The general field of beryllium metallurgy, alloys and applications have been surveyed. Cu-Be alloys have been omitted as have most items pertaining to nuclear reactor applications and toxicity problems.

1-1174. CURRENT BERYLLIUM LITERATURE: A SELECTED BIBLIOGRAPHY. Zanier D. Lane. Jan. 1958-Aug. 1959. California. Univ., Livermore. Lawrence Radiation Lab., Rept. no. UCRL 5705. 29 Sept. 1959. Contract: W-7405-ENG-48. 33p. A61-8661.

This bibliography lists selected articles on beryllium which have appeared in standard sources between January 1958 and August 1959. Subject headings are: bibliographies; chemistry of beryllium; nuclear reactions of beryllium; production, properties, fabrication and applications of beryllium; toxicity and handling of beryllium; and beryllium oxide. References to beryllium alloys and compounds have been omitted.

1-1175. CURRENT BERYLLIUM LITERATURE: A SELECTED BIBLIOGRAPHY. Zanier D. Lane. Aug. 1959 - Dec. 1960. California. Univ., Livermore. Lawrence Radiation Lab., Rept. no. UCRL-5705 (Suppl. 1). 1 May 1961. 55p. Contract: W-7405-ENG-48. A61-8661.

This bibliography lists selected articles on beryllium which have appeared in standard sources between August 1959 and December 1960. Subject headings are: bibliographies; physics of beryllium; chemistry of beryllium; beryllium isotopes; beryllium alloys, compounds, and systems; toxicity and handling; and reactor applications. References to production, properties, fabrication, metallurgy, and applications of beryllium have been omitted (except for reactor applications).

1-1176. DEVELOPMENT OF RANDOMLY ORIENTED WROUGHT BERYLLIUM SHEET. F. M. Yans, A. K. Wolff, and A. R. Kaufmann. Nuclear Metals, Inc., Cambridge, Mass., WADD TR 60-403. Dec. 1960. 93p. illus. Contract: AF 33(616)-6616, Proj. no. 7351, Task no. 73518. A61-6925.

Various factors affecting texture development in beryllium were studied in an effort to produce randomly oriented wrought beryllium sheet. Rolling experiments indicated that the specimen geometry and rolling sequences affected the textures developed during working. It was determined that, during rolling, the basal plane population parallel to the plane of the sheet increased with reduction in area and, when certain specimens are heat treated at high temperatures for short times, the basal plane population parallel to the plane of the sheet is reduced. Further rolling and annealing studies performed on bi-directionally rolled sheet indicated that, when the sheet is subjected to annealing temperatures in excess of 950°C, the location of the basal plane peak intensity is shifted and the intensity profile changes considerably, yielding a third-dimensional ductility of 1.75%. It should be noted that the same sheet in only the stress-relieved condition possesses only 0.2% third-dimensional ductility. The same textural changes were observed in sheet samples manufactured by compression rolling.

1-1177. DUCTILE BERYLLIUM ALLOYS. Final Report, 1 Sept 1959-31 Aug. 1960. Illinois Inst. of Tech., Chicago. Armour Research Foundation, Rept. no. ARF 2187-6. 20 Oct. 1960. 41p. illus. Contract: NOas-60-6036-c. AD 247 420. A61-10242.

An envelope-type microstructure prepared by liquid-phase sintering was investigated as a means of producing ductile beryllium alloys. Ternary additions of calcium, cerium, germanium, lanthanum, lithium and yttrium were made to aluminum and silver matrix alloys to evaluate their effect in promoting sinterability. Germanium was effective in producing desirable two-phase structures. Macroporosity was eliminated in compacts containing 15% or less volume of matrix by sintering under a pressure of 1000 psi. Alloying beyond the ternary level was necessary in order to reduce the hardness differential between the beryllium phase and the much softer matrices. When such a hardness difference exists, fracture of the matrix occurs before significant flow of the principal phase, with the result that ductility is poor. Aluminum additions to silver matrix alloys were effective in increasing the matrix hardness. A cylindrical compact of nominal matrix composition Ag-6Al-3Ge was tested in uniaxial compression. Properties were as follows: yield stress (0.2% offset)--52,400 psi; true fracture stress--97,000 psi; engineering fracture stress--130,000 psi; total plastic deformation--22%;

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modulus of elasticity--22 x 10^6 psi; and density--2.07 g/cc. The matrix content of this material was calculated from the density to be about 3% by volume. Its modulus-to-density ratio is 2.9 times that of steel.

1-1178. FABRICATION OF BERYLLIUM: A BIBLIOGRAPHY. Elizabeth A. Cernak. Pratt & Whitney Aircraft Div. Connecticut Operations--Canel. The Library, Middletown, Conn., CNLM-1802-14. 1 Apr. 1960. 28p. A61-11047.

This bibliography contains 147 references on the fabrication of beryllium. References are also given on the brazing, casting, cladding, extrusion and welding of beryllium and some beryllium-rich alloys. The bibliography is limited to the period 1950-1959. References are arranged alphabetically by title, with author and subject indexes provided.

1-1179. RESEARCH ON THE PROBLEMS OF DUCTILITY IN BERYLLIUM. Malcolm Basche, Sixth Quarterly Progress Report. Alloyd Research Corp., Watertown, Mass. (No Rept. no.). 30 Apr. 1959. 8p. Contract: AF 33(616)-5300. A61-6463.

This report describes the progress in the research on the production of ultra-high purity beryllium during the period 16 January through 15 April 1959. During this period work progressed on both the vacuum system and the halide reduction apparatus. The vacuum system was modified so that the four-inch diffusion pump would have an unrestricted path to the system, and thereby have a much increased pumping speed. The specimen holding jig for the electron beam zone-melting is complete and being installed in the vacuum system. The electron gun mounting assembly is almost complete and ready for installation into the vacuum chamber. Several experiments were made on the halide reduction process and a small amount of beryllium was deposited on the reaction tube.

1-1180. RESEARCH ON TECHNIQUES FOR THE PRODUCTION OF ULTRA-PURE BERYLLIUM. Joseph L. Lukesh, Laurence McD. Schetky, et al. Alloyd Research Corp., Watertown, Mass., WADC TR 58-457, Pt. I. Feb. 1959. 38p. illus. Contract: AF 33(616)-5300, Proj. no. (7351). AD 208 662. A61-6466, pt. 1.

The purpose of obtaining ultra-high purity beryllium is to find if the brittleness of the metal is due to the presence of impurities. Three methods were studied. Alkali metal reduction of the beryllium halide is feasible, though contamination by by-product sodium chloride is a problem. Experiments have shown zone-refining to be possible. Deposition of beryllium ions on the chamber walls is a serious problem. Evaporation under high vacuum seems to be the fastest method for obtaining high purity beryllium. The principal problem is obtaining a sufficiently large quantity of the metal for tests. The halide reduction method is the most promising.

1-1181. TOXICOLOGY OF BERYLLIUM: A BIBLIOGRAPHY. Eliot Dole Hutchinson, Robert D. Armstrong, et al. Rochester, N.Y. Univ. Atomic Energy Project, Rept. no. UR-570. 5 Mar. 1960. 74p. Contract: W-7401-ENG-49. A61-8668.

The title describes the contents.

SECTION E - COATINGS

1-1182. OXIDATION BEHAVIOR AND PROTECTIVE COATINGS FOR COLUMBIUM AND COLUMBIUM-BASE ALLOYS, W. D. Klopp. Battelle Memorial Inst. Defense Metals Information Center, Columbus, Ohio, DMIC Rept. no. 123. 15 Jan. 1960. 97p. illus. 63 refs. A61-10868.

Available information on the oxidation behavior of and protective coatings for columbium and columbium-base alloys is summarized and discussed. Unalloyed columbium forms a tarnish film and reacts parabolically with air or oxygen up to about 450°C. In this temperature range the protective film blisters and unprotective white Cb_2O_5 forms. Oxidation behavior is linear after formation of Cb_2O_5, the rate increasing appreciably with increasing temperature. Cb_2O_5 is solid to 1500°C. Binary additions which improve the oxidation resistance include Ti, Zr, Mo, W, Cr, and V. Ti and Zr also improve the contamination resistance of columbium. Ternary and higher alloying produces further significant improvements in oxidation behavior by promoting formation of complex oxide scales. Several of the best systems are Cb-Cr-Al, Cb-Fe-Al, Cb-Mo-Al, Cb-Ti-Al, and Cb-Ti-Cr. Improvements up to 1000-fold over unalloyed columbium are possible, but the most oxidation-resistant alloys are unfabricable. Information on protective coatings for columbium is limited. The best coatings to date appear to be a duplex LM-5 coating and a modified Ni-C coating.

1-1183. PROTECTION OF REFRACTORY METALS FOR HIGH TEMPERATURE SERVICE: THE ZINC-BASE COATING FOR NIOBIUM. B. F. Brown, R. A. Meussner, et al. Progress Report no. 1, 1 July 1960. Naval Research Lab., Washington, D.C., NRL Rept. 5550. 28 Nov. 1960. 33p. illus. A61-9796.

The protective action of a zinc-base coating on niobium is due to the formation of a tight layer of ZnO. Any breaks occurring in the oxide barrier are self-healed by the formation of additional ZnO resulting from the reaction of air with zinc vapor arriving from zinc-rich intermetallic compounds between the oxide barrier and the niobium. The zinc-niobium phase diagram has been determined sufficiently well to place the temperature limitation of the coating at 2048°F, at which temperature the most stable niobium-zinc compound decomposes. Alloy additions have not raised this ceiling while at the same time retaining the self-healing properties. No other metals have been found which are as satisfactory as zinc in forming protective coatings for niobium. Furthermore, it appears that zinc is as suitable for niobium alloys as it is for pure niobium, unless these contain high percentages of vanadium. Complex shapes can be vapor coated, but this process does not permit the admixture with the zinc of small amounts of aluminum, titanium and zirconium, which appears desirable for reliability, particularly in the range 1800° to 2000°. An appropriate approach for coatings for the range 2200° to 2300° may be to

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substitute zinc for metal A in compounds A_xNb_y which are stable at these higher temperatures. Another approach may be the use of a cladding metal which would dissolve sufficient zinc at high temperatures to maintain a ZnO barrier.

1-1184. PROTECTION OF REFRACTORY METALS FOR HIGH TEMPERATURE SERVICE: DURABILITY OF THE ZINC-BASE COATING FOR NIOBIUM. B. F. Brown, R. A. Meussner, et al. Progress Report no. 2, 1 Oct. 1960. Naval Research Labs., Washington, D. C., NRL Rept. 5581. 31 Jan. 1961. 24p. illus. A61-9795.

The effects of the coating thickness, the method of application and the temperature of application of the coating, the composition of the compounds, the temperature of the test, and thermal cycling have been examined in life tests lasting approximately 1000 hours. The beneficial effects of titanium and aluminum in the coating have been indicated and the effects of some transition metal additions are briefly reported. Some additional data are presented on the niobium-zinc system. The report also includes some observations of the redistribution of interstitial impurities in the niobium as a result of the coating and testing procedures and the results of exploratory studies on the oxidation of titanium-zinc and nickel-zinc alloys.

1-1185. REVIEW OF RECENT DEVELOPMENTS ON OXIDATION-RESISTANT COATINGS FOR REFRACTORY METALS. W. D. Klopp. Battelle Memorial Inst. Defense Metals Information Center, Columbus, Ohio, DMIC Memo 137. (n.d.) 4p. 14 refs. A61-10262.

A review of developments on oxidation-resistant coatings for molybdenum, tungsten, columbium and their alloys during the period from August through October, 1961. Developments in columbium coatings concern ductile coatings, high-temperature coatings, and fabrication of coated parts. A self-healing Al-50Sn coating for tantalum has been developed. Silicide coatings on molybdenum may be improved by alloying. New high-temperature silicide coatings for tungsten are available.

SECTION F - ELECTRIC, ELECTRONIC, AND MAGNETIC MATERIALS

1-1186. HIGH-TEMPERATURE DIELECTRIC MATERIALS. A. V. Illyn and E. C. Henry. Final Report, 1 Apr. 1959-30 June 1960. General Electric Co. Electronics Lab. and Heavy Military Electronics Dept., Syracuse, N. Y. 31p. illus. Contract: NObs-77070. A61-10310.

This is the final report on the first phase of a project to develop a high temperature capacitor. The goal of the program has been to produce a material which exhibits a dielectric constant of at least 15 and preferably greater than 50, electrical resistivity greater than 10^{11} ohm-cm, electrical Q of 1000 or greater and an RC product of 5 $M\Omega$-μf at a minimum operating temperature of 275°C. Several compositions have been evaluated, and of these, two have shown considerable promise. The two compositions, equivalent to $3SrO \cdot 2Ta_2O_5 . ZrO_2$ and $3SrO \cdot 2Ta_2O_5 . SnO_2$, were prepared and tested extensively. With the exception of electrical Q values, preliminary electrical measurements on samples of these compositions have shown that they meet the specification goals at 350°C. However, application of a continuous d-c field of 60 volts/mil at 350°C for extended periods of time has, in some cases, a degrading effect on the electrical resistivity of a number of samples. The most promising results were obtained on samples of composition $3SrO \cdot 2Ta_2O_5 . ZrO2$. Ten-mil thick samples of $3SrO . 2Ta_2O_5 . ZrO_2$ were subjected to 600 volts at 275°C for 1000 hours. At the completion of this test

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the samples still possessed their initial good properties, i. e., a dielectric constant greater than 80, an electrical resistivity of 10^{12} ohm-cm, and an RC product greater than 20. The values of electrical Q, however, were only 200. In subsequent tests of at least 60 hours each at 300°, 325°, and 350°C, these same samples exhibited dielectric constant values greater than 80, maintained resistivity values above 10^{11} ohm-cm and RC products greater than 5 megohm-microfarads. However, what remains to be done is to improve the electrical Q and the reproducibility of samples of these materials.

1-1187. PHENOMENOLOGY OF IMPURITY CONDUCTION IN SEMICONDUCTORS. E. C. McIrvine. General Atomic Div., General Dynamics Corp., San Diego, Calif., Rept. no. GA-1142. 30 Dec. 1959. 7p. Contract: NObs-77144. A61-10319.

The relationship between static dielectric constant of a semiconductor material and the critical impurity concentration above which temperature-independent impurity conduction is observed is expressed mathematically. The relationship is developed from experimental data on antimony-doped germanium, p-type germanium, n- and p-type silicon, and p-type indium antimonide.

1-1188. PROGRESS REPORT NO. XXIII. Massachusetts Inst. of Tech., Cambridge. Lab. for Insulation Research. June 1958. 55p. illus. Contracts: AF 30(635)-2872; AT (30-1)-1937; NOnr-1841(10). A61-8806.

This is a progress report on the activities of the Laboratory for Insulation Research. Work carried out in each of the following fields is covered: dielectric spectroscopy, magnetic resonance, high-field-strength research, ferroelectrics and ferromagnetics, semiconductors, single crystals, and ceramics.

1-1189. RECENT DEVELOPMENTS IN CASTING RESINS AND TECHNOLOGY FOR ELECTRICAL ENCAPSULATION APPLICATIONS. Arnold M. Molzon. Picatinny Arsenal. Plastics Technical Evaluation Center, Dover, N.J., Plastec Report 3. Nov. 1960. 31p. 90 refs. AD 247 865. A61-8437.

Important contributions to the technology of encapsulating electrical components in polymeric casting resins have recently been made by resin manufacturers, mixing- and dispensing-equipment manufacturers, electrical-equipment manufacturers, and research laboratories. The result of these advances is a steadily growing list of resins, resin modifiers, resin hardeners, casting formulations, processing techniques, processing equipment, and testing techniques. Polymeric casting materials used today include epoxy, polyester, polysulfide, silicone, polyurethane, and hydrocarbon. Most of the recent resin developments have been in the epoxy and silicone fields. Epoxy-based formulations are the most widely used materials and with polyester resins they constitute the rigid-type material. Silicones cost more than the other materials but they have better temperature capabilities (high, low, and extended range). Polysulfides and polyurethanes have found their largest use in sealing-type applications (cables, connectors) and it appears that the polyurethanes will increase in popularity at the expense of other materials because of their combination of properties such as toughness,

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thermal shock resistance, flexibility, and cold-flow resistance. Electrical testing techniques have been developed for determining the properties of casting resins while the resin is hardening and under diverse environments after it has hardened. Various systems have been developed for determining thermal stresses in cast resins and the effect of fillers, modifiers, and curing conditions on these stresses. The correlation of the results from these different systems has not been completed. Encapsulating equipment is available for automatic or semiautomatic mixing, metering, and dispensing. The development of expendible molds, plastic cartridges, and premeasured kit-type packaging has facilitated the use of encapsulating materials.

SECTION G - FABRICATION METHODS

1-1190. MANUFACTURING METHODS FOR INSULATED AND COOLED DOUBLE-WALL STRUCTURES. Interim Technical Engineering Report, 17 Dec. 1959-30 Apr. 1960. Bell Aircraft Corp., Buffalo. Niagara Frontier Div., Report no. 7-799 (I). May 1960. 252p. illus. Contract: AF 33(600)-40100, AMC Proj. no. 7-799. AD 236 733. A61-7232.

This report describes work performed from 17 December 1959, through 30 April 1960, to develop manufacturing methods, processes and related design data for double-wall structures, directly applicable to the construction of hypersonic boost-glide type vehicles. This structure will be capable of withstanding operating temperatures from 1600° to 2200°F for applicable times. Refractory type metals for use to 2600°F in the outer wall are also under investigation. This construction incorporates a cooled aluminum airframe, a protective covering of thermal insulation, and an outer wall fabricated from heat-resistant materials. Two methods of fabricating the integrally cooled inner wall skin have been selected for parallel development. One utilizes Alclad 2024 tubed-sheet and the other brazed 6951 tube-on-sheet. Progress is being made on the procurement of the tubed-sheet to BMS 2025. Satisfactory brazed tube-on-sheet has been fabricated at Bell Aircraft. A significant accomplishment has been the development and qualification of five connector designs for use in tubed-sheet headers. All of these designs

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demonstrated good sealing characteristics. A split washer design was selected based on exceptional serviceability characteristics. Preliminary design work has been completed on the end-item test component. A preliminary criteria for design and test of this component has been developed. Analytical techniques were developed for predicting heat transfer characteristics of double-wall, and for controlling coolant flow distribution through multi-parallel circuits. Experimental tests were performed to verify basic data on pressure losses and heat transfer coefficients for typical tubed-sheet circuitry. Composition of ADL-16 Insulation powders was modified to meet requirements of sea level testing at WADD. A preliminary selection of a package filter design has been made. The filling apparatus required for forcing the fine insulating powders into a metal package shell has been constructed. Haynes 25 and Inconel 702 alloys have been selected for use in brazed superalloy outer wall panels. Selection of 0.5% Ti molybdenum was made in the case of the refractory panel development work. Resistance spot-welding evaluation of molybdenum is under way, and preparations were completed for initiating molybdenum brazing work.

SECTION H - BEHAVIOR OF MATERIALS

1-1191. ANALYSIS OF TEMPERATURE DISTRIBUTION AND RADIANT HEAT TRANSFER ALONG A RECTANGULAR FIN OF CONSTANT THICKNESS. Seymour Lieblein. National Aeronautics and Space Administration, Washington, D.C., NASA TN D-196. Nov. 1959. 59p. A61-5585.

A theoretical analysis has been conducted of the one-dimensional steady-state radiant heat-transfer characteristics of rectangular fin plates of constant thickness with uniform heat source along the leading edge. The analysis was made for plates of both finite and infinite length with constant thermal properties and no convection. Results are presented in terms of the variation of the ratio of surface temperature to source temperature and of radiating effectiveness with generalized distance from the heat source for a wide range of ratios of environment sink-to-source temperatures. Results show that environment sink temperature has a pronounced effect on the temperature profiles but only little effect on the variation of radiating effectiveness. Negligible influence on the total heat radiated is also observed up to ratios of sink-to-source temperature of about 0.4. For a given sink temperature ratio, the decrease in plate temperature and radiating effectiveness with distance from the heat source depends primarily upon the magnitude of the source temperature and, to a lesser extent, on the plate thickness, emissivity, and thermal conductivity. The solutions are made applicable for a

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variety of environmental conditions through the determination of an equivalent sink temperature for the environment. Examples of special environments that can be treated in this manner and relations for determining the equivalent sink temperature for the environment are given. Design parameters for minimizing plate volume are derived, and applications of the results to practical radiator considerations such as weight optimizations and thermal stresses are indicated.

1-1192. THE EFFECTS OF RADIATION ON MATERIALS. J. J. Harwood, ed. N. Y., Reinhold, 1958. 255p. illus.

The papers included in this book were presented at a colloquium on "The Effects of Radiation on Materials" at Johns Hopkins University in Baltimore in March 1957 and deal with metals, alloys, inorganic dielectrics, semiconductors, organic and polymeric materials and materials for nuclear reactor components including fuel elements, moderators, coolants and shielding materials. Theories and concepts of radiation effects, radiation sources and measurements of radiation, and the known effects of radiation on the physical, metallurgical, mechanical, corrosion, and electrical properties are presented. In addition, there is discussion of the current thinking on behavior of organic materials, including effects of radiation upon polymeric reaction processes, e.g., graft copolymerization.

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1-1193. HIGH TEMPERATURE RADIATION RESISTANT MATERIALS. C. I. Carr and R. Miller. Progress Report no. 1, 25 July-31 Oct. 1960. United States Rubber Co., Wayne, N.J. Research and Development Dept., Research Center. 21 Nov. 1960. 14p. illus. Contract: NObs 84025. AD 259 100. A61-8839.

The object of this study is to evaluate means of extending the useful high temperature range of polyethylene for possible application at elevated temperatures in a limited radiation field. An elastomeric material was required capable of resisting limited radiation intensities in the temperature range of 300-600°F. Although adequate unaged physical properties could be obtained using crosslinked linear polyethylene reinforced with carbon black, the compounds embrittled rapidly at 350-450°F using commercial anti-oxidants. Since there is a need for elastomeric materials in high temperature applications and the usual antioxidants do not provide extended protection above about 300°F, the study has been extended to include other elastomers, oxide, and chlorinated paraffin combinations. A carbon black reinforced polyethylene containing 9 parts of Sb_2O_3 and 5 parts of polyvinyl chloride retained 92% of its room temperature tensile strength and 83% of its elongation after being aged 4 days at 450°F in air. A carbon black reinforced polyethylene containing 5 parts of both Sb_2O_3 polyvinyl chloride and cured by electron irradiation retained 73% of its 450°F tensile strength and 55% of its elongation after

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being aged at 450°F for 3 days in air. Both ethylene propylene copolymer and Butyl 035 can be protected against the effects of air aging at 350°F by employing Sb_2O_3 and Hypalon 40 in the stocks.

1-1194. INVESTIGATION OF GRAPHITE BODIES. Samuel W. Bradstreet, Leon M. Atlas, et al. Illinois Inst. of Tech., Chicago. Armour Research Foundation, WADC TR 59-706. Apr. 1960. 107p. illus. Contract: AF 33(616)-6143, Proj. no. 7350. 20 refs. AD 238 026. A61-10937.

The objectives of this work have been to correlate the properties of small multi-crystalline graphite specimens with factors known to influence them, and to use this correlation to guide the preparation of strong, nearly isotropic, non-impregnated graphite specimens having reproducible properties. The techniques of differential thermal analysis, "brittle ring" tensile testing, and dynamic and static flexural loading to temperatures above 5000°F developed as part of this work have been reported at the fourth biennial Conference on Carbon. The effects of fine aggregate packing on density, modulus, and strength are discussed, and these properties are given for experimental graphites. Bodies have now been made with coal tar pitch binders which fail in tension at above 3500 psi at room temperature and above 5000 psi at 2000°C; furfuryl alcohol-bonded bodies with a density of 1.80 gm/cc of nearly equal strength at room temperature exceed 8000 psi in flexural strength at 2250°C.

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The pyrolysis of acid catalyzed furfuryl alcohol, phenol formaldehyde, and coal tar pitch binders has been studied by differential thermal analysis and dilatometry. Reactions such as the evolution of volatiles, polymerization, and condensation appear as reproducible endothermic and exothermic peaks on the DTA records. Size and location of these peaks not only reflect differences between the binder resins, but also detect changes caused by partial pre-polymerization or by the use of different catalysts. DTA curves are also sensitive to changes in the atmospheric gas, and even to a pressure variation of one atmosphere.

Properties of molded graphites have been measured to temperatures exceeding their creep thresholds. These include thermal expansion, flexural dynamic and static modulus of elasticity, flexural strength, and tensile strength. The equipment and methods for measurement are briefly described and data are presented for typical graphites.

Diametral compressive loading of circular ring specimens is shown to be applicable to the measurement of tensile properties of such brittle materials as graphite. The relation of experimental data to that obtained by conventional techniques is presented, and the advantages of this test are shown to include its application at high temperatures.

1-1195. LABORATORY TECHNIQUES FOR DETERMINING THE HIGH TEMPERATURE STRUCTURAL BEHAVIOR OF REINFORCED PLASTICS. Richard J. McBride. Dayton, Ohio. Univ. Research Inst., WADD TR 60-797. Dec. 1960. 11p. Contract: AF 33(616)-7004, Proj. no. 7340, Task no. 73400. A61-11222.

The time-temperature studies show that in a circulating air oven a four minute time period is necessary for the entire flexural test specimen to reach test temperature (160°F or 500°F). It was concluded that the additional 4 minute exposure period resulting from testing "to" temperature produced no significant effects on the materials tested. For short-time elevated temperature evaluation of flexural properties, ten minutes exposure was determined to be optimum. Therefore, it is recommended that this time period be accepted and utilized for short-time elevated temperature testing. The data presented in this report show that it is possible to interrupt long time elevated temperature exposures with a room temperature storage period (up to 70 days duration) before testing at temperature without significantly altering the flexural property determinations from those which would be obtained from a continuous exposure. Continuous cycling from elevated to room temperature, reduces the strength properties by factors varying from 10-25% depending on the materials and type of cyclic exposure utilized.

1-1196. METAL FIBER REINFORCED CERAMICS. J. R. Tinklepaugh, B. R. Goss, et al. New York. State Univ. Coll. of Ceramics, Alfred, WADC TR 58-452, Pt. III. Nov. 1960. 77p. illus. Contract: AF 33(616)-5298, Proj. no. 7350. 18p. AD 251 929. A61-5523.

Ceramic and metallic materials may be combined in many geometric forms to produce composite materials having rather unique properties. The composite described in this report is made up of short lengths of refractory metal wire more or less randomly dispersed in a ceramic matrix. Since the composite was produced by either cold or hot pressing, there was always some orientation of these fibers in planes normal to the direction of the pressing force. Research reported previously[1-4] has demonstrated that this type of composite has a remarkable resistance to thermal shock failure as compared to the matrix ceramic alone. The flexural properties of a ceramic-metal fiber system were studied and it was found that the metal fiber does assume a part of the load. The ceramic fails when its strength is exceeded but the composite does not fail until the metal fibers are broken or pulled out of the ceramic. The test data for the alumina-molybdenum and alumina-millite-molybdenum systems were extended to 3000°F. Hafnium oxide was found to have desirable characteristics for use in a composite system.

1-1197. RESEARCH ON THE MECHANISMS OF FATIGUE.
J. C. Grosskreutz. Midwest Research Inst., Kansas City, Mo., WADD TR 60-313. Apr. 1960. 44p. illus. Contract: AF 33(616)-6383, Proj. no. 9-(7021), Task no. 73653. 14 refs. A61-10174.

Based on a critical appraisal of existing fatigue theory and experimental data, significant research areas have been outlined for the study of fatigue mechanisms. Polycrystalline aluminum and copper and single crystals of aluminum have been used to investigate dislocation densities and configurations during crack initiation and the mechanism by which cracks propagate, both on the surface of a sample and internally. Back reflection X-ray patterns show that an observable increase in dislocation density occurs within the first 0.1% of fatigue life and that a saturation density is reached after only 1% of the life. These dislocations accumulate into stable subgrain boundaries provided either that the stressing is done under a tensile preload or that the amplitude of symmetrical stressing is large enough. For small symmetrical loading (strains~0.001 for Al) a random dislocation array results with no subgrain formation. These results can be correlated with fatigue hardening behavior and possibly with the shape of the S-N curve. There is no obvious relation between the bulk behavior of fatigue induced dislocations and the formation of the initial fatigue crack which is a highly localized phenomenon. Continuous (cont.)

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observation of the surface of fatiguing samples utilizing strobe-microphotography has confirmed the accumulating evidence that cracks initiate in persistent slip bands. Tapered sections have shown that these slip bands correspond to deep notches or fissures. The propagation of the crack is observed to occur along well defined slip systems with the crack jumping from one parallel slip band to another by cross slip. Transverse sections cut through the crack have shown that the crack propagates into the volume of the metal from the surface, again via slip planes. The crack is observed to propagate generally perpendicular to the stress axis; with the available slip system, this usually results in a zigzag path. A "cloud" of slip is observed to precede the crack tip, and from this fact and the foregoing data a mechanism of crack propagation is postulated; i.e., crack propagation is a series of reinitiations in persistent slip bands.

SECTION I - WELDING AND BRAZING

No entries are made in this issue.

SECTION J - CHEMICAL AND PHYSICAL PROPERTIES OF MATERIALS

1-1198. SELECTED SHORT-TIME TENSILE AND CREEP DATA OBTAINED UNDER CONDITIONS OF RAPID HEATING. Donald P. Moon and Ward F. Simmons. Battelle Memorial Inst. Defense Metals Information Center, Columbus, Ohio, DMIC Rept. no. 130. 17 June 1960. 88p. illus. Contract: AF 18(600)-1375. 121 refs. A61-10869.

This report is a graphical presentation of selected short-time elevated-temperature strength data obtained under conditions of rapid heating. Stress-versus-temperature curves of tensile strength, yield strength, and stress to produce 1% creep strain or rupture in designated times are presented in 64 figures. Data are given for 28 alloys in sheet form, including 3 aluminum alloys, 6 titanium alloys, 2 alloy steels, 3 tool steels, 6 Cr-Ni-Fe alloys, and 8 superalloys of general interest. In addition, an extensive bibliography contains references to 121 reports and articles pertaining to test methods and equipment and to very-short-time data for these and many other materials.

1-1199. GROWTH AND MECHANICAL PROPERTIES OF FILAMENTARY SILICON CARBIDE CRYSTALS. Luke A. Yerkovich and Henry P. Kirchner. Cornell Aeronautical Lab., Inc., Buffalo, WADD TR 61-252. 32p. illus. Contract: AF 33(616)-7005. A61-11219.

In this investigation silicon carbide whiskers were grown under various experimental conditions. The strength and modulus of elasticity of several whiskers were determined at room temperature. Methods of heating the whiskers for high temperature measurements were investigated. The specific gravity of the whiskers has been inferred from measurement of the unit cell dimensions by X-ray diffraction patterns. Silicon carbide whiskers were grown by pyrolysis of methyltrichlorosilane in hydrogen. In some cases dense growths of whiskers from 1.2-1.5 cm in length and from 2-5 microns in diameter were observed. The longest whisker obtained, thus far, was 5 cm in length. The tensile strength of these whiskers ranges from 100,400 to 1,650,000 psi. The elastic strain at failure varied from 0.41-1.10% and the observed values of elastic modulus varied from 12,700,000 to 123,300,000 psi. These results indicate that silicon carbide whiskers can be strong, high modulus of elasticity materials. Much research remains to be done to improve the methods of measurement, and to define the conditions of measurement and the types of whiskers that will give the best performance as structural materials.

1-1200. PROGRESS REPORT ON DISSOLUTION AND SOLUBILITY OF METALS IN LITHIUM. B. Minushkin and H. Steinmetz. Nuclear Development Corp. of America, White Plains, N. Y., Rept. no. NDA 2118-1. 31 Mar. 1960. 21p. illus. Contract: NOnr-2857(00). 19 refs. A61-10317.

This paper is a report of the initial phase of an investigation of the kinetics of dissolution and solubility of structural metals in lithium. The theoretical background and considerations leading to the choice of experimental methods are presented. The program is limited to a study of two component systems (lithium plus pure metal) under isothermal conditions. The effects of temperature, agitation, and lithium purity are being investigated in order to establish the detailed mechanism of the dissolution process. The equipment required for this investigation has been designed, built, and operated. Techniques for stirring and sampling lithium at test temperatures, without introducing contamination, have been developed and used in preliminary tests. A method of following the dissolution process of iron using iron-59 tracer has been applied. A vacuum distillation purification system (used previously at NDA) has been put into operation to insure a supply of uniformly pure lithium. Several subsidiary problems associated with the development of the experimental techniques were also investigated. These included methods of producing thick, uniform, and adherent electroplated layers of iron (containing Fe^{59}) (cont.)

1-1200. (Cont.)

on the Armco iron liner and stirrer, and investigation of the possible effects upon specific activity of interdiffusion between iron of the plated layer and the base metal. Some preliminary tests on the solution rate of iron in lithium at 1400°F with and without stirring were performed. These were intended primarily to test the apparatus and operating procedures. Although much more work is required to provide the desired information on kinetic and solubility relationships for iron in lithium, the work done so far shows that the apparatus and techniques which have been developed will prove capable of providing this information.

1-1201. SYNTHESIS OF 4-(2, 3- EPOXYPROPOXY) PHENYLTRIMETHYLSILANE. Roy G. Neville. Lockheed Aircraft Corp. Missiles Systems Div., Sunnyvale, Calif., Rept. no. LMSD-288095. Dec. 1959. 7p. 9 refs. A61-10469.

Organic polymeric materials for high-temperature applications must possess not only thermal stability but also resistance to atmospheric oxidation. Among the most thermally stable compounds known are the aromatic silanes of the general formula R_4Si, where R represents the phenyl or biphenyl group (Refs. 1, 2, and 3). To be of use in polymer formation, such monomeric materials must possess functional groups capable of reaction, either with themselves or with other groups, to produce polymers of high molecular weight. It is known that cured Epon resins possess excellent thermal and oxidative stability, even at 500°F and above (Ref. 4). Epon-type resins possessing structures based upon silicon tetraphenyl would thus be expected to display as great, or greater, thermal stability. Almost no information exists on epoxysilicon compounds of any type, although a recent report shows an awakening interest in compounds of this class (Ref. 5). The ultimate purpose of the work described here is to synthesize the silicon analog of the Epon resin based upon 2, 2-bis(4-hydroxyphenyl)propane, the so-called bisphenol A. Before attempting the synthesis of this bifunctional compound, (cont.)

1-1201. (Cont.)

however, it was decided to work out the synthetic details of the monofunctional 4-(2, 3-epoxypropoxy)phenyltrimethylsilane (VI). This report gives details of the synthesis of the monofunctional compound from 4-bromophenol.

1-1202. THERMOPHYSICAL PROPERTIES OF SOLID MATERIALS. VOLUME III, IV, V. Alexander Goldsmith, Harry J. Hirschhorn, and Thomas E. Waterman. Illinois Inst. of Tech., Chicago. Armour Research Foundation, WADC TR 58-476. Nov. 1960. Contract: AF 33(616)-5212, Proj. no. 7381. A61-1125, vol. 3, 4, 5.

Thermophysical property data, and their variation with temperature, are presented for a great number of solid materials, based on literature published during the period 1940-1957. Each reported value is shown and annotated, and recommended "most probable value" curves are given. Materials covered include Elements, Alloys, Ceramics, Cermets, Intermetallics, Polymerics, and Composite Materials. Except for materials in the last two categories, only those melting above 1000°F are included. Properties covered include the following: Melting point, density, latent heats, specific heat, thermal conductivity, thermal diffusivity, emissivity, reflectivity, thermal expansion, vapor pressure, and electric resistivity. Each of the first four volumes is designed to be expansible, and it is expected that additional or revised data sheets for inclusion in these volumes will be forthcoming.

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Aerospace Corporation, El Segundo, California. APPLIED RESEARCH MANAGEMENT ABSTRACT BULLETIN, compiled by Literature Research Group. December 1961. [93]p. (Report TDR-930(2701-01)TN-1, Part I, No. 6) (Contract AF 04(647)-930) Unclassified report

Part I, No. 6 is a bibliography, with abstracts, from unclassified literature presented on the subject of Flight Vehicle Power. Selected references in the field of materials are also included. All references are to primary sources.

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